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PROFESSIONAL PAPERS OF THE CORPS OF ENGINEERS, U. S. ARMY.

No. 23.

REPORT

UPON

EXPERIMENTS AND INVESTIGATIONS

TO DEVELOP A

SYSTEM OF SUBMARINE MINES

FOR DEFENDING THE

HARBORS OF THE UNITED STATES.

SUBMITTED TO THE BOARD OF ENGINEERS

BY

LIEUT. COL. HENRY L. ABBOT, CORPS OF ENGINEERS,
BREVET BRIGADIER-GENERAL, U. S. A.,
MEMBER OF THE BOARD.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1881.

No. 23.

PROFESSIONAL PAPERS

OF THE

CORPS OF ENGINEERS OF THE UNITED STATES ARMY

PUBLISHED

BY AUTHORITY OF THE SECRETARY OF WAR.

HEADQUARTERS CORPS OF ENGINEERS,
1881.

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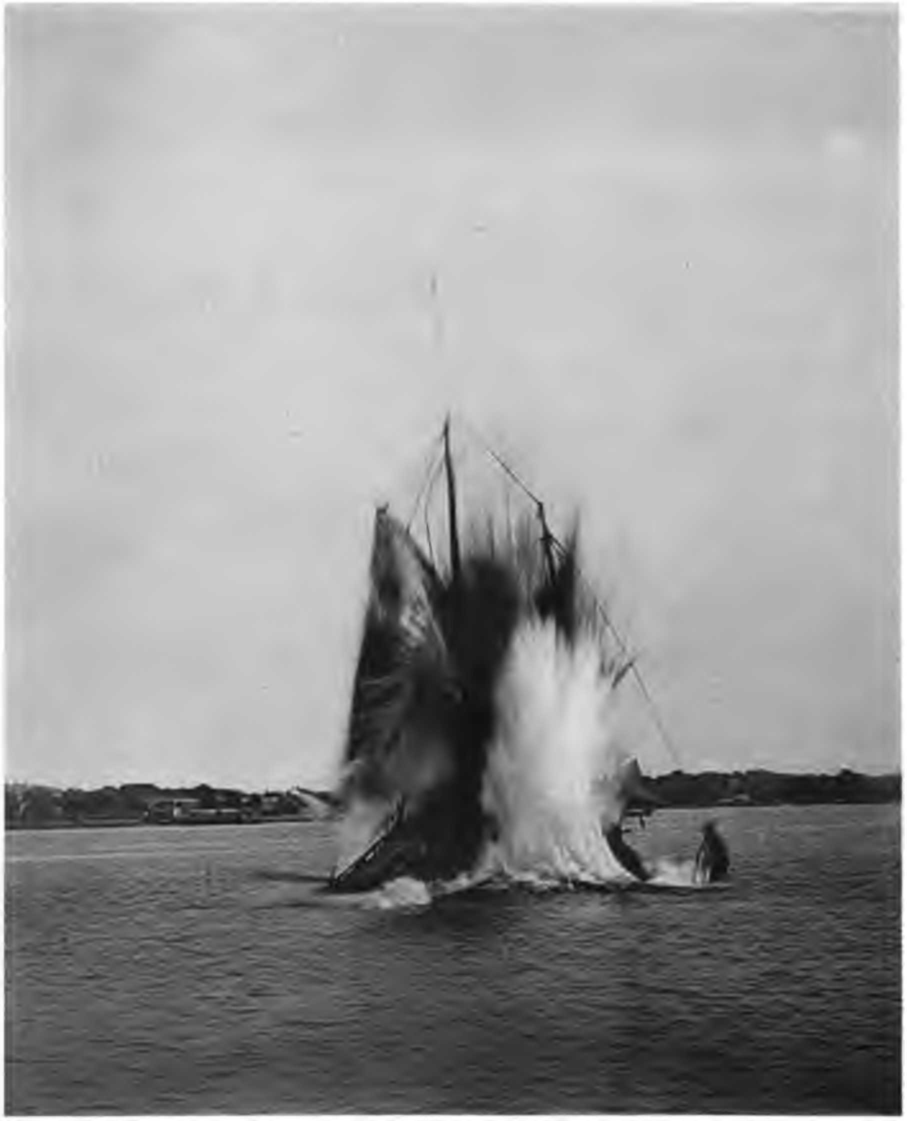

DESTRUCTION OF OLIVE BRANCH.
See page 25.

PROFESSIONAL PAPERS OF THE CORPS OF ENGINEERS, U. S. ARMY.
No. 2[illegible]

REPORT

UPON

EXPERIMENTS AND INVESTIGATIONS

TO DEVELOP A

SYSTEM OF SUBMARINE MINES

FOR DEFENDING THE

HARBORS OF THE UNITED STATES.

SUBMITTED TO THE CHIEF OF ENGINEERS, U. S. A.

BY

LIEUT. COL. HENRY L. ABBOT, CORPS OF ENGINEERS,
BREVET BRIGADIER GENERAL, U. S. A.,
MEMBER OF THE BOARD

WASHINGTON:
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LETTER OF GENERAL Z. B. TOWER

TRANSMITTING THE

REPORT TO THE ENGINEER DEPARTMENT.

OFFICE OF THE BOARD OF ENGINEERS, FOR FORTIFICATIONS, &c.,
Army Building, New York, January 31, 1881.

Brigadier General H. G. WRIGHT,
Chief of Engineers, U. S. A.,
Washington, D. C.

GENERAL :—

I have the honor to submit the following report upon submarine mining, made to this Board by Lieut. Col. H. L. Abbot, Corps of Engineers, commanding Battalion at Willets Point. Experiments and investigations to develop a system of torpedo service applicable to harbor defense having been recommended by the Board of Engineers for Fortifications early in 1869, Lieutenant-Colonel Abbot was associated with it as its executive officer for the consideration of that subject.

With a view to a commencement of the system a more complete report thereon was made in the month of October following, setting forth the experimental investigations needed for its development, and the necessity for instructing the Engineer Battalion as a body of experts to apply it to harbor defense

The approval of this project by the Chief of Engineers and by the Secretary of War, led to a long-continued series of experiments covering all the points of the programme and many others suggested during the progress of the investigations. These experiments made by Lieutenant-Colonel Abbot, with the aid of the officers and soldiers of the Engineer Battalion at Willets Point, have been thoroughly analyzed by him, and he presents his investigations connected therewith, excepting only those which it is not thought proper to make public, in the following report.

As Congress in its session of 1870–'71 added submarine mining to the duties already assigned to the Engineer troops (a part of the organization of the Corps of Engineers), it seems desirable that this valuable report should be published for the benefit of the officers of the Corps and for the instruction of the Engineer Battalion.

Very respectfully, your most obedient,

Z. B. TOWER,
Colonel of Engineers and Brevet Major General,
President of Board.

LETTER OF GENERAL H. L. ABBOT

TRANSMITTING THE

REPORT TO THE BOARD OF ENGINEERS.

WILLETS POINT, NEW YORK HARBOR,
December 11, 1880.

Colonel Z. B. TOWER,
Corps of Engineers, U. S. Army,
President of The Board of Engineers.

SIR:—

On May 5, 1869, General A. A. Humphreys, Chief of Engineers, associated me with the Board of Engineers for Fortifications, then consisting* of General J. G. Barnard, General G. W. Cullum, General Z. B. Tower, and General H. G Wright, to investigate the subject of defending harbors and navigable channels by submarine mines, and to prepare detailed plans for applying the approved methods to our sea-coast defences. As commanding officer of the Battalion of Engineers I was instructed to employ the Engineer troops in carrying out the practical trials and experiments.

In November of the same year I was directed by the Chief of Engineers to instruct the Battalion in the fabrication and preservation of torpedo material, and in its application to the defence of the coast, in conformity with the methods which might be proposed by the Board and duly approved. Confirming this action, Congress, in 1871, added submarine mining to the duties already assigned by law to the Engineer troops.

Certain definite conclusions having been reached by the Board, my most pressing duty was to embody them in the form of a Manual for the use of the Engineer troops in their practical duties as submarine miners, in the event of a war with a maritime power. This Manual was begun in 1874, and was printed as a confidential document, on the Battalion press, as fast as written. It was finally completed in 1877, and since that date it has served as the basis of instruction at the School of Submarine

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* On September 2, 1879, by authority of the honorable Secretary of War, General H. G. Wright, Chief of Engineers, dissolved this Board, and constituted the present Board of Engineers, consisting of General J. G. Barnard (absent sick), General Z. B. Tower, General John Newton, and General H. L. Abbot.

Mining at Willets Point. Being designed as a text book, it makes no mention of unsuccessful researches, and often lays down rules without discussing the grounds upon which they rest.

Having finished this task, I began the systematic reduction of the data collected in the trials. This work involved great labor, and the pressure of other duties has interfered materially with its completion. I have now, however, the honor to submit a revised copy of the first three Chapters and Appendices A, B, and C, which set forth the results already attained in respect to sub-aqueous explosions, to electrical fuzes and to modes of ignition. Proofs of these pages have been printed on the Battalion press, as fast as written, and filed with the Board at various dates beginning in 1878.

The researches now reported have been general in their nature, covering ground of interest to officers of the Corps, and others, engaged in harbor improvements, rock blasting, and similar works; and, in my judgment, there is no reason why the results should not be made public.

The remaining chapters of my Report to the Board will treat of the special investigations undertaken to develop the best patterns of submarine mines and *matériel;* of insulated torpedo cables; of electrical apparatus for operating submarine mines; of the electric light in harbor defence; and of movable fish torpedoes, which remain under control of an operator on shore. These chapters being necessarily of a confidential nature, the manuscript should, in my judgment, be printed on the Battalion press solely for use at the School of Submarine Mining at Willets Point.

For the foregoing reasons, I would respectfully suggest that the three chapters and appendices, transmitted herewith, be forwarded to the Chief of Engineers, with a recommendation that they be printed for distribution as one of the Professional Papers of the Corps of Engineers.

Very respectfully, your obedient servant,

HENRY L. ABBOT,
Lieutenant-Colonel of Engineers,
Brevet Brigadier-General, U. S A.,
Member of The Board of Engineers.

EXPERIMENTS AND INVESTIGATIONS

TO DEVELOP

A SYSTEM OF SUBMARINE MINES.

CHAPTER I.

SUB-AQUEOUS EXPLOSIONS.

The Dynamometer.—The Ring Apparatus.—The Crate Apparatus.—Manœuvering Apparatus.—Wooden Torpedo Target.—Iron Torpedo Target.—Torpedo Cases.—Mortar powder.—Mammoth powder.—Oliver powder.—Cannon powder.—Musket powder.—Sporting powder.—Safety Compound, O. P. C.—Discussion of the formulæ.—Large Detonating Primers.—Air Chamber within the Torpedo.—Effect of Recoil.—Summary of results with Explosive Mixtures.—Dynamite (or Giant powder) No. 1.—Gun-cotton.—Dualin.—Lithofracteur (or Rendrock).—Dynamite (or Giant powder) No. 2.—Vulcan powder.—Mica powder.—Nitro-glycerine.—Hercules powder.—Electric powder.—Designolle powder.—Brugere (or Picric) powder.—Explosive Gelatine.—Mixed Explosives.—Discussion of the formulæ.—Effect of wetting the charge.—Effect of freezing the charge.—Effect of long storage.—Air space in Torpedo.—Material between the charge and the water.—Sympathetic explosion of neighboring mines.—Summary of results with Explosive Compounds.—Depressions in target.—Effect of recoil in target.—Experiments under ice.—Experiments with targets.—The Oberon experiments.—Experiments at Carlscrona, Sweden.—Other miscellaneous experiments.—Conclusions as to effective torpedo range.

When, in 1869, the investigations which form the subject of this report were undertaken, the destruction of a vessel through the agency of a sub-aqueous explosion was a comparatively new problem; the general laws governing the action of the forces developed were unknown; and the subject, therefore, demanded the most thorough and systematic treatment.

The simplest manner of arriving at practical conclusions would, doubtless, have been to make actual trials upon a modern ship of war; or upon a hull correctly representing it not only in strength but also in mass, upon which the destructive effect of a sudden shock must largely depend. Such trials would have far exceeded the funds available; and it therefore became necessary to devise some other method.

After much deliberation a systematic course of experiment was undertaken, designed to throw light upon the unknown laws governing the transmission of the energy developed by the explosion through the water to the vessel, and to determine the impulse required to effect her destruction. In other words, the whole subject was considered to demand close experimental analysis; the laws governing the transmission of the shock through the fluid were to be discovered; the relative merits of different explosives were to be compared; and, finally, the resistance to be expected from the best class of modern hulls was to be determined. The problem how to blow up a ship of war would then admit of the definite discussion usually applied to works of practical engineering.

This manner of treating the subject has involved much labor and much study; but, as the services of the Engineer troops have been available in making the practical trials, the expense has been inconsiderable; and the results attained are of so general a nature as to admit of future application to new conditions, which may be expected from the rapid improvement now taking place in every branch of the art of war.

The theory of the investigation being thus based upon precise measurement, the first step was to provide apparatus for accurately registering the effects of a subaqueous explosion. This accomplished, it would be possible to deduce the general laws governing the transmission of the shock, and the effects of variations in explosive, in charge, in distance, in direction, in submergence, in modes of ignition and in the mass of the body receiving the blow.

APPARATUS FOR MEASUREMENT.

Before proceeding to state the conclusions reached upon the several points, the various apparatus will be considered in order—viz, the dynamometer; the rings; the crate; and the iron target designed to represent approximately a section from a ship of war.

The Dynamometer.—As early as the year 1851, the late General Rodman, acting upon a suggestion of Maj. W. Wade, devised his well-known pressure-gauge for measuring the intensity of the explosive force of gunpowder when burned in cannon. It consisted of a hollow cylinder of iron closed at the base; a screw plug for closing the mouth of this cylinder; a copper gasket to form a gas-tight joint between these parts; a specimen of copper to be indented, resting upon the inside base; an indenting-tool; an indenting piston moving through an axial hole in the screw plug, and firmly united to the indenting-tool; and a gas check of copper to prevent the entrance of gas round the piston. This apparatus was placed within the gun, at the bottom of the bore. The "pressure" to which it had been subjected by the explosion was inferred from the indentation made in the specimen of copper by the indenting-tool.

In the year 1865 Major King applied this gauge to measuring the "pressures" exerted by small charges of mortar powder exploded under water in its close vicinity. He found it necessary to enlarge the area of the piston-head in order to obtain measurable cuts with his comparatively slight pressures. Although his charges averaged less than 30 pounds—ranging from 10 to 50 pounds—he reported "secondary cuts" in several cases, which he attributed to the elasticity of the water.

About the year 1869 Capt. William H. Noble, Royal Artillery, a member of the

British Committee on Explosives, modified the Rodman apparatus by suppressing the edge of the indenting-tool; that is, he replaced the copper disc by a small copper cylinder, to be compressed in the direction of its length by a movable piston. To this apparatus the name of Crusher Gauge was given.

To determine the "pressures" corresponding to the different indications of these instruments only one method—that of General Rodman—has heretofore been employed. Samples of the discs or cylinders of copper are subjected to the action of a testing machine, which by a slow motion, entirely under control, can be made to apply any desired pressure. These results, when tabulated, form a scale of pressures and corresponding cuts or compressions, which is used to interpret the mechanical work performed by the explosion upon the copper submitted to its action.

In a paper read before the National Academy of Sciences, in 1865, Prof. W. H. C. Bartlett, of the United States Military Academy, criticised this method of estimating the pressure due to the action of gunpowder, upon the ground that it ignores "the distinction between the measure for *intensity* and that for its *work*. The real difficulty lies in our ignorance of the laws which connect the intensity of copper resistance and of gas elasticity with the plug penetration. If these laws were accurately known, it would be easy to find the maximum of gas pressure, by the Rodman process, from the known depth of plug penetration and the resistance due to the unit of penetration. In the absence of these laws it would be better to modify the experiments by inserting a number of plugs around the circumference of the same cross section of the gun, made at different distances from the mouth, and keep the plugs in their places by suitable dynamometers strained to different degrees; and after firing, find that plug which has made but a faint indentation on the copper. The indication of the dynamometer on this plug would be the measure of the maximum elastic force of the gas." He also considers the form of the Rodman cutter to be objectionable. "It would be much better to use a conical point, and rely upon a filar micrometer with great magnifying power in the eye-glass, to measure the surface diameter of the penetration."

The foregoing facts were known to me in 1869, when it became my official duty, as executive officer of the Board, to prepare a dynamometer for measuring the intensity of action developed by sub-aqueous explosions large enough to be practically used for the destruction of shipping. The general method above indicated, evidently offered advantages over any other feasible plan; but two difficulties were apparent, one mechanical, and the other mathematical. The former consisted in modifying the Rodman gauge:

I. To exclude water, or at least to neutralize its effects, when the apparatus was submerged to depths as great as 100 feet.

II. To prevent, even in the vortex of the largest explosion, the hammering motion of the piston, which occasioned the secondary cuts observed by Major King.

III. To increase the delicacy of the indications, so that the apparatus should register much smaller intensities of action than those developed in the bore of a cannon.

The mathematical problem consisted in deducing from the mechanical work of the explosion, as registered at the yielding point of the apparatus, a correct knowledge of the destructive power developed.

The mechanical problem was solved in the gauge represented on Plate I, Figs. 1 and 2. Water is excluded by a stout rubber cap, held in place by a rubber band fitting into the groove (*A*). Should any accidental leak occur, its effect is neutralized by cutting the base of the piston by four planes (*B*) parallel to the axis, so as to allow the water to pass freely around it.

To prevent any hammering of the piston, a clutch (*C*) is attached to its base in such a way as freely to allow a downward motion, but effectually to prevent any return, by engaging in the screw threads cut around the interior of the cylinder. The original form of this clutch, devised in 1869 and used until the end of the season 1872, was improved at that date upon a suggestion of Sergeant Nolty, Company D, Battalion of Engineers, and his modification is shown on the plate.

The requisite degree of sensitiveness was secured by employing cylinders of lead, of five different sizes (Plate I, Fig. 3), to register the work of the explosion as transmitted by the piston. To further extend the scale, three different sizes of piston were adopted, having sectional areas of 0.100, 0.385, and 0.785 square inches. The gauges containing them were designated No. 1, No. 2, and No. 3, respectively; but in 1872 the intermediate size was abandoned as unnecessary

Lead was chosen as the best metal for these cylinders, after a series of special experiments begun on a testing machine belonging to the Watertown Arsenal, and concluded in June, 1870, on a much superior instrument at Rock Island Arsenal. They convinced me that copper is too hard for use in registering very small pressures, even when a large diameter of piston is employed, and that lead is suitable for the purpose.

The precaution was taken to have all the lead cylinders for the projected torpedo trials, made at Rock Island Arsenal from a single lot of carefully selected original manufacturers' pigs. They were formed by casting and compression, a small hole being left in the die to allow the surplus lead to escape. General Rodman, then in command of the arsenal, suggested this method of preparation, and to his kindness is due so great precision of manufacture that no differences in specific gravity could be detected among the specimens.

As already stated, five sizes of these cylindrical leads were adopted, which for

Fig. 1. Socket and Gauge.
Scale, 1:2.

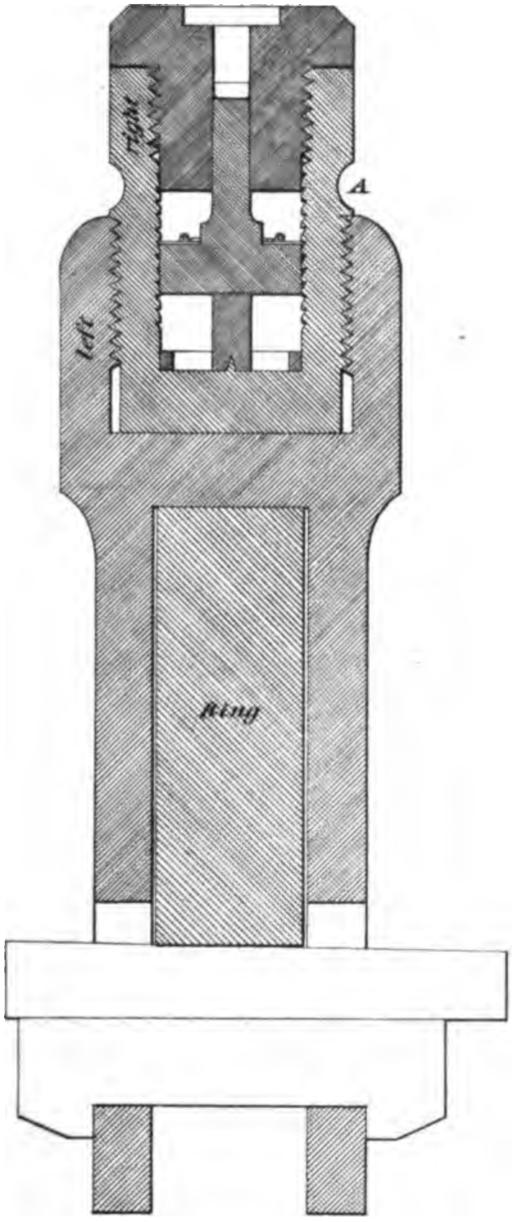


Fig. 2. Gauge Piston.
Full Size.

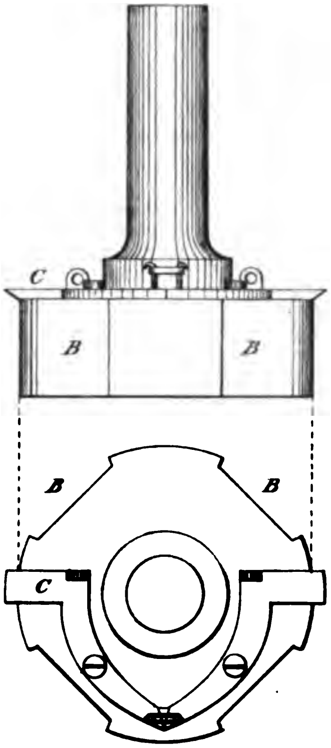
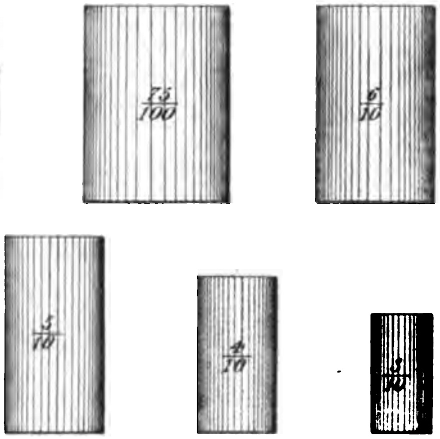


Fig. 3. Lead Cylinders.
Full Size.



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convenience will be designated by their diameters. The following are the exact dimensions, also shown to the eye on Plate I, Fig. 3.

$\frac{75}{100}$ lead; length, 1.006 inches; diameter, 0.75 inches.
$\frac{6}{10}$ lead; length, 1.004 inches; diameter, 0.60 inches.
$\frac{5}{10}$ lead; length, 1.003 inches; diameter, 0.50 inches.
$\frac{4}{10}$ lead; length, 0.799 inches; diameter, 0.40 inches.
$\frac{3}{10}$ lead; length, 0.601 inches; diameter, 0.30 inches.

To measure the compressions of these cylinders, use was made of a standard scale having one fixed and one sliding contact piece, and reading by a vernier correctly to one-thousandth of an inch. The rapidity and accuracy of this method leaves nothing to be desired.

The mathematical problem of so interpreting the lead compressions effected by a sub-aqueous explosion as to derive from them a correct idea of the destructive effect likely to be exerted upon a ship, requires careful consideration.

At the instant of explosion, a certain quantity of gas, depending upon the nature and weight of the charge, is developed with a degree of suddenness varying with its chemical composition and the mode of ignition. The free expansion of this gas being resisted by the inertia developed in the water, a certain amount of mechanical work is instantaneously performed, resulting in the formation of a chamber filled with the highly heated products of the chemical reaction. The pressure of the surrounding water, joined to the original impulse, gives a rapid motion to this chamber along the line of least resistance, which in general coincides with the vertical drawn through the centre of the charge. A rush of gas and water into the air is the result; which, in the case of a large charge exploded near the surface, often presents an imposing spectacle.

There is in this phenomenon an analogy to what occurs at the discharge of a cannon. The line of least resistance corresponds to the axis of the bore, while the water around plays the part of the metal of the gun.

A vessel in the vicinity may be exposed to three distinct dangers: 1st, Its hull, embedded in the aqueous cannon, may be ruptured by the initial shock transmitted from molecule to molecule through the fluid. 2d, should the hull be situated near the vertical through the charge, its resistance may prove to be less than that of the superincumbent water; and the line of least resistance may thus be deflected from its normal direction, and traverse the vessel. 3d, In the case of the enormous charges sometimes employed in submarine mining, the waves generated by the explosion may rack the vessel beyond its power of endurance, or by rising amidships may even break her in sunder.

Unless an actual vessel be available for the experiment, it is evident that the pressure gauge can only be arranged to measure the first of these three causes of destruction. The instrument virtually forms part of the aqueous cannon, and chiefly registers the kinetic energy transmitted from molecule to molecule of the fluid. Fortunately, this is the primary cause of rupture; and conclusions based upon the gauge indications may therefore be accepted as the best attainable of the destructive force of the explosion.

To rupture the bottom of a vessel is to perform mechanical work: that is, there must be an effective motion of the point of application of the force along the line of its direction. This motion being much greater than in the bursting of a cannon, time becomes a more important element. Hence, in comparing different explosives, or the same explosive under varying conditions as to distance, submergence, mode of ignition, etc., regard must be had to the amount of mechanical work to be performed, rather than to the intensity of the forces developed; but it must not be forgotten that a certain amount of the latter is needful to overcome the resistance of the hull suddenly, before the available energy can be dissipated upon the water, or upon a general lateral movement of the ship. In fact, it is possible to conceive that with the same potential energy an explosion may be so sudden and short-lived as to fail to supply the continuous force necessary to effect the destruction of the hull; or, on the other hand, that its force may be developed so slowly as to be expended in general harmless motion.

It would appear, therefore, that the mean intensity of the force acting upon the ship during the time of the explosion, is the quantity most important to be determined.

As has been clearly pointed out by Professor Bartlett, the Rodman gauge only registers the kinetic energy developed in the piston by the explosion. It throws no light either upon the time of action or upon the law governing the variation of pressure while passing from zero at the beginning of the explosion to zero at its end. We simply learn from it the sum of the products of the varying intensity of the force into the corresponding differentials of path through which the piston moves.

Although the problem of interpreting this result is similar theoretically for copper and lead, the hardness of the former metal offers a certain advantage, which considerably simplifies the investigation in its case. It was on account of this advantage that General Rodman was able to form a practically useful scale by employing a testing machine. He reasoned—and was lead to introduce a valuable mode of measurement thereby—that the explosive intensity of action of the gas, in passing from zero to its maximum, drove his indenting-tool into the copper with such force as to develop a resisting surface sufficient to prevent any further motion while passing from its maximum intensity to zero. In other words, he believed that the length of his cut chiefly depended upon the maximum pressure, and hence could be considered a measure of that pressure and an index of its probable effect upon the bore of the gun. He endeavored to prove the correctness of this reasoning by subjecting copper specimens to a second explosion identical with the first, the edge of the indenting-tool being placed in the previous cut. No increase of length was noted. This experiment has since been verified in England with the crusher-gauge, as is shown by the following table, giving the pressures indicated in the 12.5-inch rifled muzzle-loading gun, with a charge of 130 pounds of 1.5-inch cubical powder and a projectile weighing 800 pounds. The pressure is always estimated from the total shortening.

Repeated impulses on copper.

Number of round.	Muzzle velocity.	Pressure in tons per square inch at various points from end of bore.						Remarks.
		0 inch.	12 inches.	24 inches.	36 inches.	48 inches.	60 inches.	
1	1401	22.3	21.4	20.3	20.1	14.1	12.0	New copper cylinders.
2	1417	22.7	22.8	20.4	21.1	14.9	12.1	Same coppers as used in round 1.
3	1408	22.7	22.9	20.5	21.3	16.1	12.3	Same coppers as used in rounds 1 and 2.
4	1424	22.7	22.9	22.4	23.6	17.1	12.7	Same coppers as used in rounds 1, 2, and 3.

Freely granting the correctness of these experiments, their pertinence to the argument for maximum pressure may well be questioned. Why should further motion be communicated to the indenting-tool when supported by a surface cut in the copper, which has resulted not only from the maximum action but also from the combined effect of all the other actions? It is also to be noted that these experiments have been made with a slow-burning variety of gunpowder; and that the results might be different with a finer and quicker grade. For a still stronger reason this might be true with the detonating compounds, the most important class of explosives to be studied for the torpedo service.

In making my experiments with lead cylinders at Rock Island Arsenal, I became satisfied that the theory just stated was not true for lead discs or cylinders—at least for the smaller sizes—since a marked variation could be made in the shortening by varying the time of applying the pressure, and of its continuance. Still, as the needed delicacy of scale would not admit of the use of copper, the difficulty could not be avoided.

The following table exhibits some special experiments, made by me at Rock Island Arsenal, to throw light on the subject. The pressure was applied as rapidly as possible, instantly withdrawn, and the shortening noted. The pressure was then re-applied, and kept steadily on for two minutes, the lead gradually shortening during this period as shown by the figures.

Continued pressures on lead.

Diameter of cylinder.	Pressure.	Time of applying first pressure.	Original length.	Length after first application of pressure.	First shortening.	Length after two minutes.	Second shortening.
Inches.	*Pounds.*	*Seconds.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
0.4	500	45	0.803	0.671	0.132	0.518	0.153
	1,000	30	0.803	0.370	0.433	0.259	0.111
0.5	1.000	45	1.000	0.736	0.264	0.567	0.169
	2,000	30	1.000	0.387	0.613	0.265	0.122
0.6	1,000	45	1.010	0.886	0.124	0.819	0.067
	1,000	30	1.012	0.893	0.119	0.826	0.067
	2,000	45	1.012	0.517	0.495	0.350	0.167
0.75	2,000	40	1.015	0.802	0.213	0.650	0.152
	3,000	45	1.015	0.576	0.439	0.400	0.176

Similar trials of lead discs under the Rodman indenting-tool showed a steady increase in the length of cut, corresponding to the time of continuance of the pressure.

My projected method of operating offered one important advantage over the usual gun experiments; and upon it I depended to overcome the increased difficulty due to the use of lead. By placing several pressure-gauges containing leads of different dimensions, under identical circumstances respecting a given sub-aqueous explosion, it would be possible to obtain exactly the *corresponding compressions* due to a given impulse; and by varying the area of the pistons, other corresponding series could be secured. The data would thus admit of many checks and of thorough analysis.

Acting upon these views, a very careful scale was made with the testing-machine, upon the Rodman plan, to serve for purposes of preliminary comparison. The following table exhibits the results. For the figures showing the shortening of the smallest lead, I am indebted to the kindness of Lieut. W. P. Butler, Ordnance Department, who took the observations after my departure from Rock Island.

Lead shortening by testing machine.

Pressure.	$\frac{3}{16}$ lead.	$\frac{4}{16}$ lead.	$\frac{5}{16}$ lead.	$\frac{3}{8}$ lead.	$\frac{14}{16}$ lead.
Pounds.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
100	0.002	0.004	0.002	0.000	.....
200	0.037	0.014	0.005	0.002	0.003
300	0.121	0.033	0.006	0.005	.....
400	0.244	0.078	0.019	0.007	0.003
500	0.296	0.148	0.046	0.010	.....
600	0.365	0.219	0.089	0.016	0.005
700	0.405	0.292	0.138	0.034	.....
800	0.410	0.354	0.200	0.064	0.008
900	0.430	0.415	0.234	0.098	.....
1,000	0.430	0.431	0.288	0.127	0.016
1,100	0.435	0.468	0.351	0.155	.....
1,200	0.450	0.494	0.415	0.189	0.04
1,300	0.458	0.507	0.437	0.236	.....
1,400	0.462	0.529	0.476	0.263	0.071
1,500	0.473	0.541	0.510	0.318	.....
1,600	0.474	0.552	0.539	0.333	0.128
1,700	0.478	0.565	0.569	0.389	.....
1,800	0.480	0.572	0.581	0.417	0.153
1,900	0.483	0.580	0.600	0.436	.....
2,000	0.486	0.590	0.618	0.461	0.204
2,500	.....	0.620	0.667	0.573	0.300
3,000	.....	0.639	0.729	0.631	0.413
3,500	.....	0.654	0.745	0.671	0.472
4,000	.....	0.657	0.762	0.709	0.530

During the summer of 1871, many comparative trials of the different leads were made upon the plan above indicated; and it was found that the relative compressions obtained with the testing machine—which required from 30 to 60 seconds to effect—bore no simple relation to those produced by sub-aqueous explosions. The difference in time of action was evidently so great as to radically change the conditions. Impressed with the necessity of eliminating the effect of this time element in deducing a scale, I devised the following apparatus:

Upon a beam forming part of the side of a large shed, was swung, by a piece of No. 9 galvanized iron wire, a heavy sledge hammer head weighing 23.38 pounds. The pivot was arranged so as practically to eliminate friction. By counting the number of oscillations in a given number of seconds, the length of the pendulum from the pivot to the centre of percussion was determined from the usual formula, viz:

$$l = \frac{l' \text{ (seconds)}^2}{\text{(oscillations)}^2}$$

For Willets Point l' is 3.25936. The length of the pendulum (l) was found to be 7.07 feet. Upon the side of the building, behind the pendulum, a large quadrant of a circle was described from the pivot as a centre, and was accurately graduated to degrees. A block of granite, weighing between two and three tons, was next prepared to receive and hold rigidly in position a socket, into which a pressure gauge was firmly screwed. This was carefully placed so that the centre of the indenting piston was opposite the centre of percussion, and in contact with the pendulum when the latter hung vertically. A piece of tracing tape, attached to the hammer head, was passed over a small pulley so that the head could be readily raised to any mark of the graduated arc, up to ninety degrees inclusive.

When this tape was cut by a pair of scissors it is evident that the head would impinge upon the end of the gauge piston with a velocity due to a fall represented by the versine of the arc through which it had been raised; and by noting the recoil, and preventing by hand a second blow, all the data could be secured for computing exactly the mechanical work corresponding to the shortening of the lead subjected to the shock.

The first experiment was made with this apparatus in November, 1871; and its precision even exceeded my anticipations. The compressions of similar leads receiving similar blows differed very slightly from each other, even when measured with a scale reading to one-thousandth of an inch. By extending the observations, the shortening due to known blows of such force as to include all the desired portion of the scale was readily determined. The following table exhibits the data thus secured.

Lead shortening by pendulum.

Fall of pendulum.	Kinetic energy. (Net.)	$\frac{2}{16}$ lead.	$\frac{4}{16}$ lead.	$\frac{6}{16}$ lead.	$\frac{8}{16}$ lead.	$\frac{12}{16}$ lead.	Remarks.
°	*Foot pounds.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	
3	0.226	0.010	0.010	0.007	0.006	0.004	The recoils for maximum falls are: For $\frac{2}{16}$ lead, 1°.0 For $\frac{4}{16}$ lead, 2°.3 For $\frac{6}{16}$ lead, 2°.9 For $\frac{8}{16}$ lead, 2°.9 For $\frac{12}{16}$ lead, 4°.5
5	0.630	0.032	0.024	0.018	0.013	0.009	
10	2.496	0.090	0.071	0.053	0.036	0.025	
15	5.612	0.160	0.129	.....	.....	.....	
20	9.932	0.232	0.191	0.148	0.115	0.075	
25	15.460	0.300	0.249	.....	.....	.....	
30	22.090	0.357	0.309	0.251	0.187	0.138	
35	29.870	0.404	0.363	.....	.....	.....	
40	38.610	.....	0.411	0.365	0.275	0.208	
45	48.370	.....	0.470	.....	.....	.....	
50	58.970	.....	0.521	0.463	0.363	0.274	
55	70.380	.....	0.560	.....	.....	.....	
60	82.510	.....	0.591	0.560	0.448	0.340	
70	108.610	.....	.....	0.636	0.527	0.396	
80	136.350	.....	.....	0.703	0.587	0.450	
90	164.990	.....	.....	0.744	0.637	0.500	

The following table, selected at random from the experiments made upon $\frac{4}{16}$ leads, will give a fair idea of the relative and absolute precision of the two methods.

Comparison of pendulum and testing machine.

Testing machine. 800 pounds.			Testing machine. 900 pounds.			Pendulum. 35°			Pendulum. 40°		
Shortening.	Δ	Δ²	Shortening.	Δ	Δ²	Shortening.	Δ	Δ²	Shortening.	Δ	Δ²
0.370	+.016	0.00026	0.433	+.018	0.00032	0.365	+.010	0.00010	0.397	−.014	0.00019
0.380	+.026	0.00067	0.446	+.031	0.00096	0.338	−.017	0.00028	0.416	+.005	0.00002
0.327	−.027	0.00072	0.373	−.042	0.00176	0.362	+.007	0.00004	0.395	−.016	0.00025
0.338	−.016	0.00026	0.387	−.028	0.00078	0.363	+.008	0.00006	0.420	+.009	0.00008
.....	......	....	0.425	+.010	0.00010	0.360	+.005	0.00002	0.421	+.010	0.00010
.....	......	....	0.426	+.011	0.00012	0.343	−.012	0.00014	0.406	−.005	0.00002
.....	......	....	.....	......	....	.....	......	....	0.417	+.006	0.00003
.....	......	....	.....	......	....	.....	......	....	0.417	+ 006	0.00003
1.415		0.00192	2.490		0.00405	2.131		0.00067	3.289		0.00075
Mean 0.354 ± 0.009			Mean 0.415 ± 0.008			Mean 0.355 ± 0.003			Mean 0.411 ± 0.002		

In the summer of 1878 it became necessary to test a second lot of $\frac{4}{10}$ lead cylinders. The old pendulum having been dismounted, an entirely new one was prepared; and advantage was taken of it to determine, by experiment, whether the recoil measured, practically, all the kinetic energy of the blow not represented by the lead shortening. This was done by varying the weight of the pendulum, and comparing the results.

Comparison of different pendulums.

Kinetic energy. (Net.)	Shortenings of $\frac{4}{16}$ leads.				Remarks.
	Old leads. Pendulum scale 1871.	Old leads. Heavy pendulum 1878.	New leads. Heavy pendulum 1878.	New leads. Light pendulum 1878.	
Foot pounds.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	PENDULUM OF 1871. Weight 28.88 pounds. Length 7.07 feet. Maximum swing 42°±, HEAVY PENDULUM, 1878. Weight 24.97 pounds. Length 7.04 feet. Maximum swing 40°. LIGHT PENDULUM, 1878. Weight 12.406 pounds. Length 7.04 feet. Maximum swing 55°.
0. 33	0. 014	.....	.....	0. 012	
0. 66	0. 025	0. 020	0. 022	.....	
1. 32	0. 043	.....	.....	0. 042	
2. 66	0. 075	0. 071	0. 067	.....	
2. 96	0. 081	.....	.....	0. 075	
5. 25	0. 123	.....	.....	0. 119	
5. 96	0. 134	0. 124	0. 124	.....	
8. 15	0. 167	.....	.....	0. 161	
10. 56	0. 199	0. 186	0. 191	.....	
11. 66	0. 211	.....	.....	0. 202	
15. 75	0. 252	.....	.....	0. 243	
16. 42	0. 259	0. 256	0. 259	.....	
20. 38	0. 294	.....	.....	0. 289	
23. 48	0. 318	0. 317	0. 323	.....	
25. 53	0. 333	.....	.....	0. 327	
31. 13	0. 372	.....	.....	0. 369	
31. 50	0. 375	.....	0. 372	.....	
31. 72	0. 376	0. 372	.....	.....	
37. 20	0. 409	.....	.....	0. 400	
41. 02	0. 431	0. 435	0. 428	.....	
Mean discrepancy..............		0. 005	0. 005	0. 005	

This table explains itself; and, although there appears to be a small instrumental discrepancy of five-thousandths of an inch between the results of 1871 and 1878, the truth of the assumption that there is no sensible loss from friction, resistance of the air, heat developed, etc., is sufficiently established. Each shortening is the mean of two experiments, which in no case differed from each other more than a few thousandths of an inch.

The manner of forming the working scales from the pendulum observations of 1871 will now be explained in detail. It was applied, of course, to each of the five varieties of lead cylinder, separately.

The mean of all the observed shortenings due to similar blows was adopted as the true shortening for that blow. The corresponding energy was computed from the observed fall and recoil of the pendulum by the formula:

$$(1) \qquad W = w\, l\, (\cos \vartheta_{,} - \cos \vartheta)$$

In which W denotes the net kinetic energy to which the shortening of the lead was due; w the weight of the pendulum; l the length of the pendulum; ϑ the angle of fall and $\vartheta_{,}$ the angle of rebound—both measured from the point of rest. The angles of recoil were practically very small, rarely exceeding 2° or 3°. The figures given in the table on page 22 were deduced by this process, and exhibit the data upon which the scales were based.

By dividing the net kinetic energy in this table, successively, by the area in square inches of each of the three piston heads, the energy per square inch of surface to be exposed to the action of the sub-aqueous explosions became known for each of the three sizes of gauge adopted.

From these data fifteen curves were plotted, the ordinates being the lead shortening and the abscissæ the corresponding energy per square inch of surface exposed to the explosion. The measured points of these curves being quite close together, they afforded every facility for accurate interpolation; thus rendering it easy to construct tables giving the energy per square inch corresponding to every $\frac{1}{1000}$ of an inch of shortening for any of the five sizes of lead in any of the three varieties of gauge.

This new method of constructing a scale for measuring the effects of an explosion possesses the following advantages over that of the testing machine:

I. The confusion between energy and pressure is avoided. The results are expressed in foot pounds, the usual measure of mechanical work; which is really the quantity measured by the Rodman gauge.

II. The shortening of the lead is produced instantaneously; thus the circumstances under which an explosion acts are more closely represented than by the process of the testing machine, which usually requires at least 30 seconds to effect the same result. With a metal so soft as lead this is an enormous advantage—indeed, as the results proved, it is essential to success.

III. The new process is more exact, and involves the use of no rare and expensive apparatus. A little experience with the testing machine will convince any one that, in so delicate work, the results are effected by an unavoidable personal equation of the operator. Indeed, I lost an entire day's observations at Rock Island Arsenal by employing an unpractised mechanic; and it was only when General Rodman kindly supplied a man who had had a long training that the satisfactory results exhibited in the table on page 20 were obtained.

There is one difficulty, however, in the pendulum method which requires attention. In truth, it affects both methods equally; but by treating the indications as maximum pressures, General Rodman avoided its discussion in his gun problem. This difficulty is the following:

The mechanical work per unit of surface which an explosion is capable of performing is not the best quantity for consideration in discussing its probable destructive power upon a ship of war. The reasons for this view have been already given, when considering the general modes of action of sub-aqueous explosions; and the conclusion there reached, that the mean intensity of the force acting upon the unit of surface during the time of the explosion is the true quantity from which to estimate the probable effect, suggests the next step to be taken here. Some method of passing from the measured energy to a corresponding mean intensity of action must be sought.

In this connection several points merit attention; some of which, although they have been already mentioned, will be briefly recapitulated.

I. A heavy shock upon the ship is of vital importance, because if this be deficient the available energy may be dissipated in useless motion instead of crushing the hull. Although the actual duration of the action of a sub-aqueous explosion upon a vessel is known to be very short, to be effective it must perform mechanical work. To obtain some precise data upon this subject, a schooner was blown up at Willets Point in the summer of 1878. (See frontispiece.) She was anchored in water 15 feet deep. Two torpedoes, each a beer keg containing 50 pounds of mortar powder, were suspended 10 feet apart and 3 feet below her bottom, amidships. They were submerged 7 feet. Six cameras were placed at a distance of about 500 feet, so arranged that, by the aid of electricity, instantaneous views could be taken at the pleasure of the operator. The time of explosion and of dropping each camera slide was electrically recorded on a field chronograph. The torpedoes were exploded simultaneously. A picture taken one-tenth of a second thereafter showed the bow and stern plunged in the water and the middle of the vessel raised about 16 feet in the air. The masts were still vertical, and the jet of water had reached a height of about 70 feet. The second picture, taken 1.5 seconds after the explosion, showed a column of water 160 feet high containing many fragments of the wreck. The third picture, 2.3 seconds after the explosion, showed the jet at its maximum, 180 feet high; the air was full of fragments, but apparently none had yet begun to fall back to the water. The fourth picture, about 3.3 seconds after the explosion, exhibited a descending mist; the water agitated by heavy splashes of fragments; and the site of the wreck shrouded by a cloud of smoke. The fifth picture, taken a second later, showed only a thin cloud of mist and smoke, with no evidences of violent action remaining. Thus the total destruction of the schooner had only consumed about 0.1 of a second; and the whole exhibition of power only about 4.5 seconds. The exceedingly short duration of the destructive action left no doubt upon my mind that upon the *mean*, and not upon the *maximum*, intensity of action will the useful effect probably depend.

II. The mean pressure may always be derived from known mechanical work by dividing the latter by the path of the point of application, expressed in linear units, along the line of direction of the force.

III. By restricting the length of the path—*i. e.*, by opposing the motion by a body offering a high resistance, a closer idea may be derived of the actual available intensity of action of a sudden blow than by making use of a more yielding body.

IV. In the present case each lead offers a different resistance; and hence, if the actual motion of the piston head be adopted, five scales not directly comparable among themselves will result. This difficulty is illustrated, and a direct comparison is exhibited between the methods of the pendulum and of the testing machine by the following table. The figures in the third and fifth columns are computed by dividing by the lead shortenings the net energies producing them. These figures should compare with those in first column; and they probably would do so were it not for the difference in time during which the force was acting.

Comparison of pressure and shock on lead.

Maximum pressure applied by testing machine.	$\frac{1}{16}$ lead.		$\frac{11}{100}$ lead.	
	Observed shortening by testing machine.	Corresponding mean pressure by pendulum.	Observed shortening by testing machine.	Corresponding mean pressure by pendulum.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*
100	0. 004	240	.....	...
200	0. 014	283	.....	...
300	0. 033	345	.....	...
400	0. 078	432	0. 003	640
500	0. 148	557	0. 004	690
600	0. 219	681	0. 005	738
700	0. 292	828	.....	...
800	0. 354	968	0. 008	840
900	0. 415	1, 108	.....	...
1, 000	0. 431	1, 140	0. 016	975
1, 100	0. 468	1, 231	.....	...
1, 200	0. 494	1, 296	0. 048	1, 375
1, 300	0. 507	1, 330	.....	.....
1, 400	0. 529	1, 392	0. 071	1, 563
1, 500	0. 541	1, 432	0. 100	1, 700
1, 600	.....	.....	0. 128	1, 858
1, 800	.....	.....	0. 153	2, 017
2, 000	.....	.....	0. 204	2, 262
2, 500	.....	.....	0. 300	2, 728
3, 000	.....	.....	0. 413	3, 405
3, 500	.....	.....	0. 472	3, 785

V. The Rodman scale, based upon the very small indenting motion of his cutter into a copper disc, is not only suitable for the present purpose, but it also has the advantage of having been generally used in ordnance investigations, making it in some sort a recognized standard, which, however, should be understood to express *mean* not *maximum* pressures.

For these reasons I decided to adopt the indentation of Rodman's indenting-tool into his discs of copper, as the uniform path to be used in translating my energies into mean pressures.

To do this it was necessary to employ the pendulum with Rodman's indenting-tool and copper discs, and thus to determine for the blows which had been delivered upon the leads the corresponding indentations made in the copper. This was accordingly done, the indentations in feet (I) being derived from the cuts (C) measured in inches by the following formula, which results from the known angle (ϑ) made by the two parts of the edge:

$$(2) \qquad I = \frac{C}{24 \tan \frac{1}{2} \vartheta}$$

The following table exhibits the results of these experiments, ϑ being 163° 30′ for the indenting-tool employed:

Observations with Rodman's indenting-tool.

Pendulum of 1871.		Kinetic energy. Net. (W.)	Observed length of cut.	Indentation determined by equation (2). (I.)
Fall.	Recoil.			
Degrees.	*Degrees.*	*Foot pounds.*	*Inches.*	*Foot.*
3	0.0	0.226	0.195	0.00118
5	0.0	0.630	0.290	0.00175
10	0.5	2.496	0.480	0.00290
15	2.0	5.532	0.640	0.00390
20	3.0	9.743	0.760	0.00460
25	5.0	14.860	0.900	0.00544
30	5.8	21.290	1.000	0.00604
35	6.2	28.930	1.130	0.00682
40	7.2	37.370	1.210	0.00731
45	8.0	46.800	1.285	0.00776
50	9.0	57.000	1.380	0.00834
55	10.0	67.960	1.440	0.00870
60	11.0	79.610	1.500	0.00906

A careful study of the third and fifth columns of this table, by the graphical method, led me to perceive that the indentation of the copper (I) was a simple function of the net kinetic energy of the pendulum (W) of the form:

$$I = B\,W^{\frac{1}{3}} \qquad (3)$$

The method of least squares was employed to determine the most probable value of B. The foregoing table supplied 13 equations of condition; which, being allowed weight proportional to the square roots of the number of observations from which they were derived, gave the normal equation:

$$0.277772 = 128.8221\ B$$

Substituting in equation (3) the resulting value of B, (0.002156), the following general value of I results:

$$I = 0.002156\ W^{\frac{1}{3}} \qquad (4)$$

The following table sufficiently establishes the correctness of this empirical formula; not only by the accordance of its indications with the observations given in the last table, but also by the precision with which, combined with equation (2) it predicts the observed lengths of the cuts. The last two columns show a surprising correspondence between scales of absolute pressure obtained by methods so radically different as those of Rodman and my own. Very possibly the samples of copper used by me were a little harder than those he employed; and had the former been subjected to trial on the testing machine, perhaps the accordance might have been still closer. The actual discrepancies fall within variations often observed between different samples of copper, and the comparison of the two methods certainly tends to confirm the practical value of the Rodman scale, except, perhaps, for low pressures.

The circumstance that so simple an equation could be deduced for the indentation was of great practical advantage in these investigations, as will be seen hereafter.

Comparison of pressure and shock on copper.

Kinetic energy of pendulum. (W.)	Length of cut.		Copper indentations.			Corresponding pressures.		
	Observed.	Computed by Eq. (4) & (2).	Observed.	Computed by Eq. (4) = I.	Difference.	Testing machine. Rodman's tables.	$\frac{W}{I}$.	Diff.
Foot pounds.	*Inches.*	*Inches.*	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*
0. 226	0. 195	0. 217	0. 00118	0. 00131	−0. 00013	285	172	+113
0. 630	0. 290	0. 306	0. 00175	0. 00184	−0. 00009	533	340	+193
2. 496	0. 480	0. 485	0. 00290	0. 00292	- -0. 00002	1, 180	855	+325
5. 532	0. 640	0. 631	0. 00390	0. 00380	+0. 00010	1, 880	1, 451	+429
9. 743	0. 760	0. 762	0. 00460	0. 00460	0. 00000	2, 584	2, 116	+468
14. 860	0. 900	0. 877	0. 00544	0. 00530	+0. 00014	3, 315	2, 803	+512
21. 290	1. 000	0. 969	0. 00604	0. 00597	+0. 00007	4, 040	3, 566	+474
28. 930	1. 130	1. 095	0. 00682	0. 00662	+0. 00020	4, 867	4, 371	+496
37. 370	1. 210	1. 193	0. 00731	0. 00721	+0. 00010	5, 660	5, 186	+474
46. 800	1. 285	1. 286	0. 00776	0. 00777	−0. 00001	6, 463	6, 025	+438
57. 000	1. 380	1. 373	0. 00834	0. 00830	+0. 00004	7, 280	6, 872	+408
67. 980	1. 440	1. 456	0. 00870	0. 00880	−0. 00010	8, 110	7, 725	+385
79. 610	1. 500	1. 534	0. 00906	0. 00927	−0. 00021	8, 890	8, 590	+300

Having thus settled upon a plan for translating the energy tables into corresponding mean pressure tables, it remained, before doing so, to check, and if needful correct, the former by results obtained from sub-aqueous explosions.

The apparatus by which this was accomplished will soon be described; but at present a correct comparison will be assumed, and the results will be considered. It was found:

I. That when leads of different sizes were subjected in similar gauges to the same shock, the energy tables entered with the observed compressions failed to indicate the same number of foot pounds. In every case the smaller the lead the larger the indication.

II. That analogous discrepancies attended the use of gauges of different sizes.

III. That these discrepancies were much larger with explosive mixtures than with explosive compounds.

The interpretation of these results, in the light of the experiments already described, was obvious.

The time during which the mean force acted upon the leads was longest with the testing machine, much shorter with mechanical mixtures, shorter still with chemical compounds, and shortest of all with the pendulum. The larger the surface of piston head exposed the more difference did this variation in time occasion.

The true method of obviating the difficulty was equally clear.

The larger the lead and the smaller the piston head, the less would be the effect of variation in time of exposure. Hence, the $\frac{75}{100}$ lead and the No. 1 gauge were adopted as the standards. The absolute difference in time of action between the pendulum and a sub-aqueous explosion must be very small; making it probable that, with so large a lead and so small a piston head, no marked difference results from the variation. This conclusion was warranted by the reduction in the observed discrepancies as the size of the leads increased.

As to the other leads and gauges, correction ratios for reducing their indications to those of the standard could easily be derived from special shots fired for the purpose.

This was done by two different methods, both for explosive mixtures and for explosive compounds. The sub-aqueous explosions were surrounded with six gauges held rigidly in position. In the first method the alternate gauges and leads were varied for the same shot; in the second method many shots were fired under identical conditions and registered by different gauges and leads. About 170 shots were fired, with this among other objects in view, during the autumns of 1871 and 1872; and their results are given in detail in Appendix A—compare shots 65 to 180 and 239 to 292.

The discussion of these data was laborious and interesting, but as the correctness of the deduced values is sufficiently shown by the figures in the appendix, it is not necessary to give the analysis here in full. The general results are the following:

As already stated, the shortening of the $\frac{75}{100}$ lead exposed in the No. 1 gauge was assumed to correctly indicate the energy per square inch of surface exposed, when translated by the energy tables already described.

When the No. 1 gauge was used with other leads, before their indications would correspond with those of the $\frac{75}{100}$ lead a correction to the tables was needed to allow for the excess of time of exposure over that of the pendulum blow. These corrections proved to be simple ratios, constant for each lead—the errors being greater with slow burning than with detonating explosives. The following are their numerical values:

$\frac{75}{100}$ leads: multiplier for compounds, 1.000; for mixtures, 1.000
$\frac{6}{10}$ leads: multiplier for compounds, 0.786; for mixtures, 0.620
$\frac{5}{10}$ leads: multiplier for compounds, 0.670; for mixtures, 0.411
$\frac{4}{10}$ leads: multiplier for compounds, 0.752; for mixtures, 0.278
$\frac{3}{10}$ leads: multiplier for compounds, 0.647; for mixtures, 0.195

The apparent irregularity of the corrections for compounds was due to the variation in the length of the leads; which, as already stated, was for the first three, 1 inch; for the $\frac{4}{10}$ lead, 0.8 of an inch; and for the $\frac{3}{10}$ lead, 0.6 of an inch.

When the larger gauges were used, the above correction ratios for the energy tables remained unchanged, and correctly reduced the indications of the smaller leads to those of the $\frac{75}{100}$ lead; but it now became necessary to take into account the increased dimensions of the pistons. The following were these dimensions:

No. 1 gauge: weight of piston, 0.286 pounds; area, 0.100 square inches.
No. 2 gauge: weight of piston, 0.474 pounds; area, 0.385 square inches.
No. 3 gauge: weight of piston, 0.607 pounds; area, 0.785 square inches.

For detonating compounds, the tabular results shown by different gauges were reduced to those of No. 1 by multiplying by the ratio of the masses of the pistons, viz:

No. 1 gauge: correction ratio, 1.0000
No. 2 gauge: correction ratio, 0.6034
No. 3 gauge: correction ratio, 0.4712

For explosive mixtures, the ratio of the areas exposed to the shock was also found to enter the formula, giving:

No. 1 gauge: correction ratio, $1.0000 \times 1.0000 = 1.0000$
No. 2 gauge: correction ratio, $0.6034 \times 0.2597 = 0.1567$
No. 3 gauge: correction ratio, $0.4712 \times 0.1274 = 0.0600$

Having by these ratios revised the energy tables so that an explosion registered the same results no matter what leads or gauges were used, a corresponding set of pressure tables was prepared by dividing the tabulated energies by the corresponding values of I in equation (4).

It may appear that unnecessary labor was devoted to the subject of scale determination, but it must be remembered that the problem to be solved involved the accurate measurement of pressures extending through a very wide range; and that to correctly deduce the laws of variation, it was essential that records should be made by the explosions which should not only admit of determinate measurement, but which also should be directly comparable among themselves. At the outset it was not easy to fix limits to what might be required. After extended experiments, the use of the $\frac{6}{10}$ and $\frac{5}{10}$ leads and of the No. 2 gauge were discontinued—but by fully discussing the subject it is probable that better results were obtained than a less laborious study would have afforded.

In concluding this branch of the subject it may be remarked that the final practical conclusions are independent of the absolute unit adopted. The general scope of the investigation involved the determination of certain definite mechanical effects which are produced by sub-aqueous explosions; the generalization of the results in mathematical formulæ; and, finally, the determination of which of these effects correspond to destructive blows to a first-class modern armored vessel. The nature of the unit is thus eliminated in the final conclusions. In other words, when the amount of lead shortening corresponding to a fatal blow has been experimentally discovered, and when the distance in any direction from any sub-aqueous explosion at which a similar shortening will be produced, has been determined, the dangerous range of that torpedo becomes known, quite independently of the theoretical nature of the unit of measurement employed.

In this respect, the subject is much simpler than the similar investigation of the strains upon cannon; which necessarily involves numerical units, since the known strength of the metal to resist strains of extension and compression must be considered, in adjusting the dimensions of the different parts of the gun.

Having adopted a suitable pattern of dynamometer, the next step was to devise apparatus for holding several of these instruments rigidly in position, at certain known positions with respect to the centre of sub-aqueous explosions—the depth of the whole system below the surface being variable at pleasure. This was accomplished by the Rings and the Crate—heavy iron frames supported by buoys. Each will be considered in turn.

The Ring Apparatus.—This apparatus (Plate II), the same in principle as that devised by Major King in 1865, consisted of a stout ring of wrought iron, made strong enough to resist the strains to which it was to be subjected, and of suitable attachments. The latter consisted of six sockets for holding the ring gauges in place; a supporting and a guard strap; charge attachments; a buoy, with a gauge socket at its lowest point; and a wire connecting rope, with a buffer and gauge sockets to be inserted as desired.

Four sizes of rings were employed—3, 4, 5, and 8 feet, respectively, in interior diameter. They were made of the best wrought iron that could be procured in the market. The first three sizes were 1.5 inch in thickness, and 4.5 inches wide in the plane of the ring. The 8-foot ring, which was designed for exceptional use, was made of lighter iron, 1.0 inch by 4.5 inches, in order to reduce the weight to the supporting power of buoys computed for the 5-foot ring.

The six sockets, into which the ring gauges were screwed, were attached by straps projecting at their bases, which clasped the rings and were secured by gibs and keys at the points where they projected outward beyond the ring. These sockets were attached at shallow seats cut 60° apart, thus holding the gauges symmetrically in the plane of the ring, and directed toward the centre. Two were at the level of the charge, two were above, and two were below.

The supporting strap was a stout iron band which clasped the ring midway between the two upper gauges, and was held in position by gibs and keys on the outside of the circumference. A small exterior ring supplied a convenient means of connecting this strap to the wire rope by an ordinary shackle, and of attaching a 3-inch hemp rope used for lowering and raising the apparatus. Experience soon led to the use of a second similar strap at the bottom of the ring, to receive a guard rope for use in case of accident.

The charge, in a suitable case, was held in the centre of the ring by four diagonal lashings, usually of galvanized iron wire, which were attached to small eye-bolts at opposite points of its circumference.

The ring was supported in the water, with its plane vertical, by a wrought iron buoy of suitable size. This was cylindrical in form, 2 feet in diameter and 6 feet in height, and was made of $\frac{3}{16}$-inch iron. At the bottom it terminated in a cone of $\frac{1}{2}$-inch iron, 1 foot in height, at the vertex of which a gauge socket and attachment ring for the wire rope were provided. A scale painted on the side enabled the submergence of the charge and gauges to be accurately determined.

The buoy and ring were connected by wire rope 1 inch in diameter. This usually consisted of separate 10-foot lengths, united by ordinary shackles. At as many of these junctions as was desired, cable sockets designated to receive gauges could be inserted.

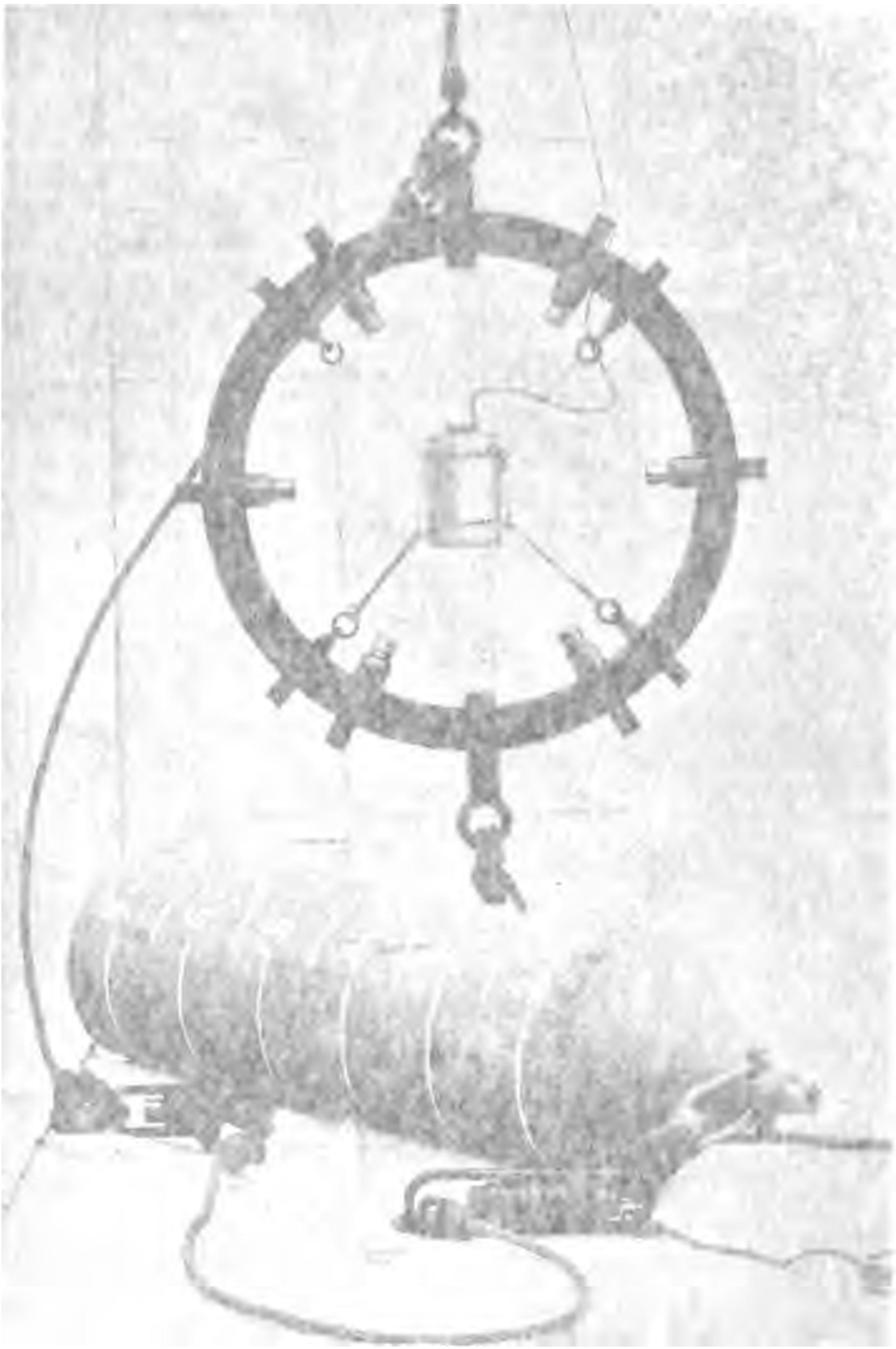
Experience with large charges soon demonstrated the necessity for some elastic member in the connections. This was supplied by a buffer, so arranged that the sudden strain was made to compress five vulcanized rubber rings, each 1 inch thick. By this device great additional strength was added; and the whole apparatus was often thrown more than 50 feet into the air without injury to any part.

The following table gives all needful information as to the weights of the apparatus:

	Pounds.
Weight of 3-foot ring without attachments	231
Weight of 4-foot ring without attachments	301
Weight of 5-foot ring without attachments	381
Weight of 8-foot ring without attachments	416
Weight of ring attachments complete—large gauges	232
Weight of ring attachments complete—small gauges	205
Weight of 10-foot length of wire rope	33
Weight of cable gauge socket and gauge, complete	38
Weight of buffer	38
Weight of buoy and gauge, complete	656
Displacement of buoy	1,300

It will be understood from the foregoing description that when the ring was supported in the water, ready for the explosion, two of the gauges, numbered 3 and 4, were in the same horizontal plane as the charge; and that two, numbered 1 and 2, were above, and two, numbered 5 and 6, were below this plane; all placed symmetrically round the charge and pointing toward it, at points 60° apart. Also that one gauge was placed vertically over the charge at the lowest point of the buoy; and as many others as might be desired at known distances between the latter and the charge. These gauges, external to the ring, were numbered consecutively downward, that at the buoy being always No. 7.

The Crate Apparatus.—The apparatus described above was only suited for measuring the energy developed by an explosion in the immediate vicinity of the torpedo, and at certain points vertically over it. For a full discussion of the subject it was essential to study the gauge indications at points situated at considerable lateral distances above, at the level of, and below the charge. It was assumed, and experiment abundantly confirmed the truth of the assumption, that to give trustworthy



[illegible] was made of ⅜-inch iron. At the bottom it terminated in a cone of [illegible] height, at the vertex of which a gauge socket and attachment [illegible] were provided. A scale painted on the side enabled the submergence [illegible] and gauges to be accurately determined.

[illegible] buoy and ring were connected by wire rope 1 inch in diameter. The [illegible] composed of separate 10-foot lengths, united by ordinary shackles. At [illegible] junctions as was desired, cable sockets designated to receive [illegible] inserted.

[illegible] with large charges soon demonstrated the necessity for [illegible] connections. This was supplied by a buffer so arranged [illegible] was made to compress five vulcanized rubber rings, each [illegible] great additional strength was added, and the whole apparatus [illegible] 20 feet into the air without injury to any part.

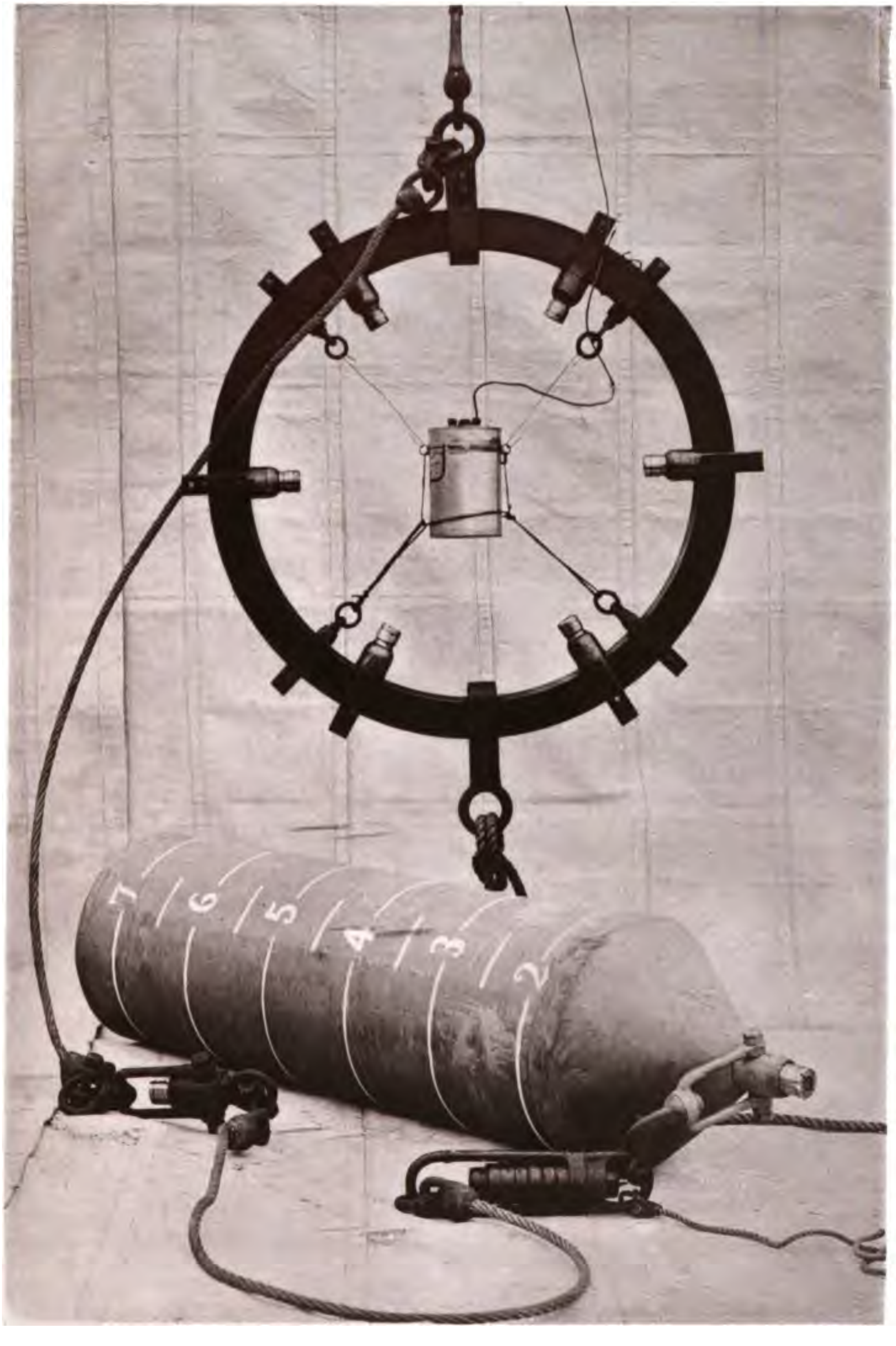
The following table gives some useful information as to the weights of the [illegible]

	Pounds
[illegible] 10-foot ring with attachments	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
Weight of ring with attachments complete—large gauges	[illegible]
Weight of ring with attachments complete—small gauges	[illegible]
Weight of 10-foot length of wire rope	[illegible]
Weight of each gauge socket and gauge complete	[illegible]
Weight of buoy	[illegible]
Weight of buoy and gauge complete	[illegible]
Displacement of buoy	1,3[illegible]

It will be understood from the foregoing description that when the ring was supported in the water, ready for the explosion, two of the gauges, numbered [illegible] and [illegible], were in the same horizontal plane as the charge; and that two, numbered 1 and 2, were above, and two, numbered 5 and 6, were below this plane; all placed symmetrically round the charge, and pointing toward it at points [illegible] apart. Also one gauge was placed vertically over the charge at the lowest point of the buoy, and as many others as might be desired at known distances between the latter and the ring. These gauges, external to the ring, were numbered consecutively downward, that at the buoy being always No. 7.

The Crate Apparatus.—The apparatus described above was only suited for measuring the energy developed by an explosion in the immediate vicinity of the charge and at certain points vertically over it. For a full discussion of the subject it was essential to study the gauge indications at points situated at considerable distances above, at the level of, and below the charge. It was assumed, and [illegible] abundantly confirmed the truth of the assumption, that to give [illegible]

PLATE II.



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results these gauges must be held rigidly in position. To fulfil these conditions the Crate was devised in 1869.

It consisted (Plate V) of a wrought iron frame 50 feet long by 10 feet wide by 10 feet deep, all measured in the clear. The torpedo was secured by wire lashings in the middle of this frame.

To reduce the weight to the minimum, iron only 0.5 of an inch in thickness was employed, the needful strength being given by adjusting the width of the several plates according to the relative strains which it was anticipated would be thrown upon them. The planes of these several plates, produced, all passed through the centre of the torpedo, so that the eye placed at this point saw only knife edges in every direction.

The details of construction were the following: The four long edges of the parallelopiped onconsisted of single plates of 0.5-inch iron, the width being 5 inches at the ends, and gradually increasing to 11 inches at the middle. These plates were connected by nine perpendicular transom frames, the iron of each having the same width as the longitudinal plates at their junctions. The distance between these transoms, measured from the centre, was respectively 10, 5, 5, and 5 feet in each direction.

The connections between the plates and transoms were strongly riveted upon the usual angle iron principle. The third frame from each end was diagonally braced, both to give additional stiffness and to afford a good hold for a stout rod extending from the middle point upward through the top transom and terminating in a ring for supporting the Crate. Experience also showed the necessity of diagonally bracing the middle transom to the angles of the adjacent frames, at the top of the Crate

Sockets for receiving gauges were attached at every point of junction of the transoms and main plates—thus providing for 36 gauges, placed symmetrically above and below a horizontal plane passing through the longitudinal axis.

The Crate was supported by two buoys of ¼-inch iron. They were double riveted, braced, and stayed; being cylindrical in form, 3.5 feet in diameter, 11 feet in height, and terminating at the bottom in a cone 2 feet in height, with a socket for receiving a gauge and shackle at the vertex.

Every explosion was thus registered upon thirty-eight gauges, all rigidly held at known distances from the centre of the torpedo.

The buoys and Crate were connected by 6-inch hawsers. By varying the absolute and relative lengths of these cables any desired depth and angle could be given to the axis.

The following were the weights of this apparatus, as constructed:

	Pounds.
Weight of the Crate	9,169
Weight of the attachments complete	720
Weight of a buoy, complete	2,117
Displacement of a buoy	7,400

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This apparatus developed enormous strength to resist explosions, and fully accomplished the objects for which it was designed. A model made for the Centennial Exhibition at Philadelphia, in 1876, is preserved in the Torpedo Museum, at Willets Point.

Manœuvring Apparatus.—The rings were handled from a raft (Plate III), consisting of two wooden pontons of the reserve equipage of the army, placed side by side and united by short balk held in position by iron straps. A small windlass and boom strongly braced by iron rods was provided near the stern of one of the pontons for raising and lowering the ring. Two men working the crank could easily raise about 800 pounds.

This raft accommodated about a dozen soldiers, with the torpedoes designed for a day's firing. It was rowed to the position selected, towing the buoy behind it and carrying the ring slung to the boom.

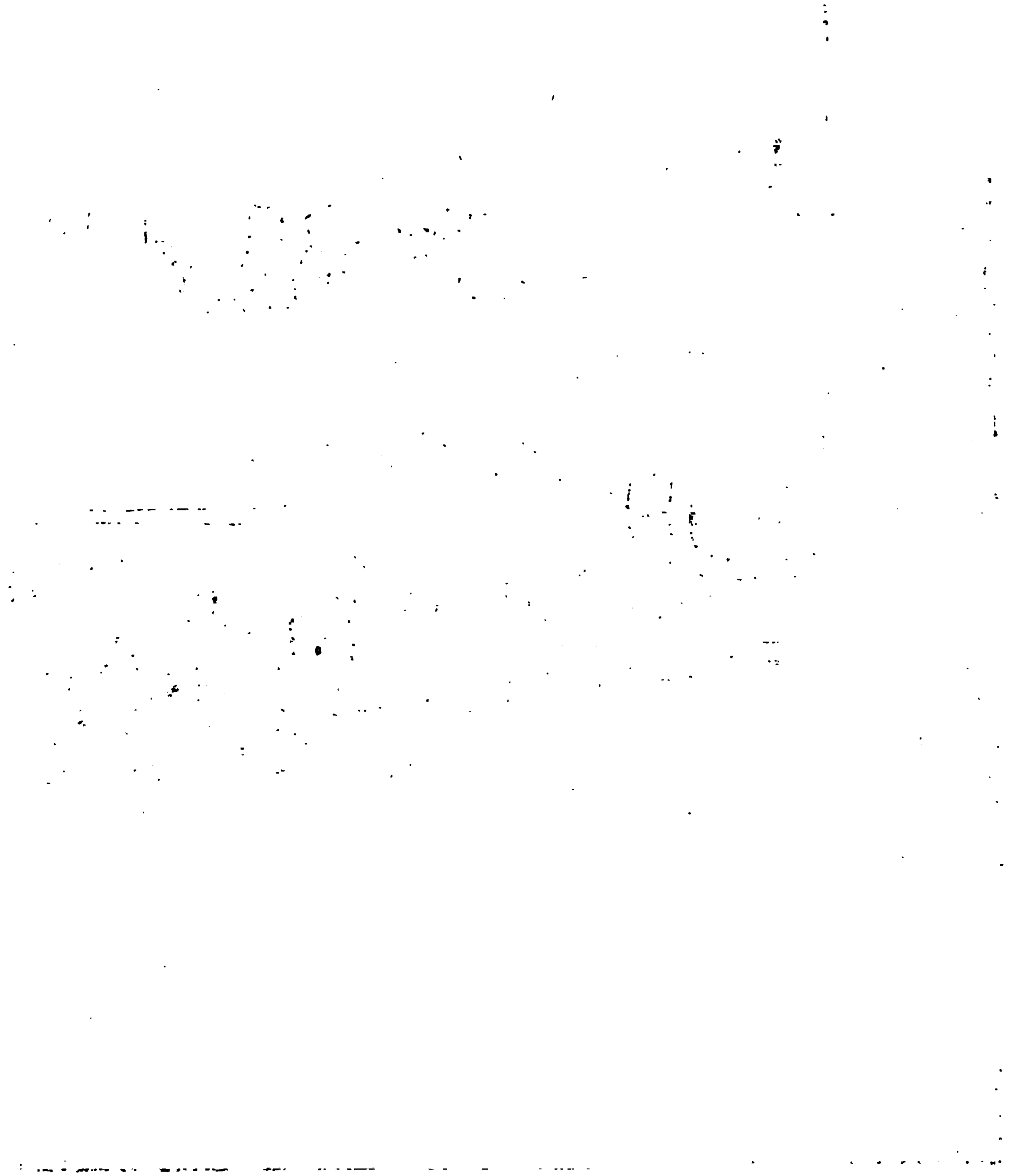
The method of operating was the following: The torpedo and gauges were attached to the ring by the aid of a small boat containing the electrical machine used for firing. The ring was lowered until its weight was supported by the buoy. The raft and boat separated to a safe distance. The explosion was effected. The ring was raised by its hemp lowering rope; the gauges were removed and re-charged with fresh leads; and the next shot was fired in like manner.

Many gunpowder charges, weighing from 25 to 300 pounds, were thus successfully exploded. The usual submergence of the torpedo was 35 feet, varying from 20 to 100 feet. The larger charges often threw the whole apparatus into the air; and, at first, breakages were frequent. Experience, however, soon suggested expedients for lessening the risks, and but few losses of material and no serious accident occurred.

In many of the gunpowder charges two gauges were placed inside the torpedo and recovered by 10-foot lengths of wire rope attached to projecting handles. A 3-inch hemp rope attached to the other end of the wire rope enabled the gauge to be drawn into the ponton after the explosion. This plan could not be used with explosive compounds, as the tremendous intensity of action, even of the smallest charges, upset the steel pistons and rendered it impossible to open the gauges.

The same intensity of action limited the weight of the charge in the case of the explosive compounds. Five pounds was the maximum which could be used, safely, in tin cases in the 5-foot ring—any increase developing a tendency to upset the pistons of the ring gauges.

The difference of action between explosive mixtures and compounds was further shown by the nature of the breakages. The former tended to part the wire rope connecting the ring and buoy; to dash the gauge sockets and ring together; and, in general, to do injury at a distance from the charge. The latter acted locally, upsetting the gauges, breaking the ring, and cutting off the lowering rope.



[illegible] explosions and fail[illegible] A model [illegible] presented [illegible]

[illegible] The [illegible] the reserve [illegible] placed [illegible] A small windlass [illegible] could easily raise [illegible]

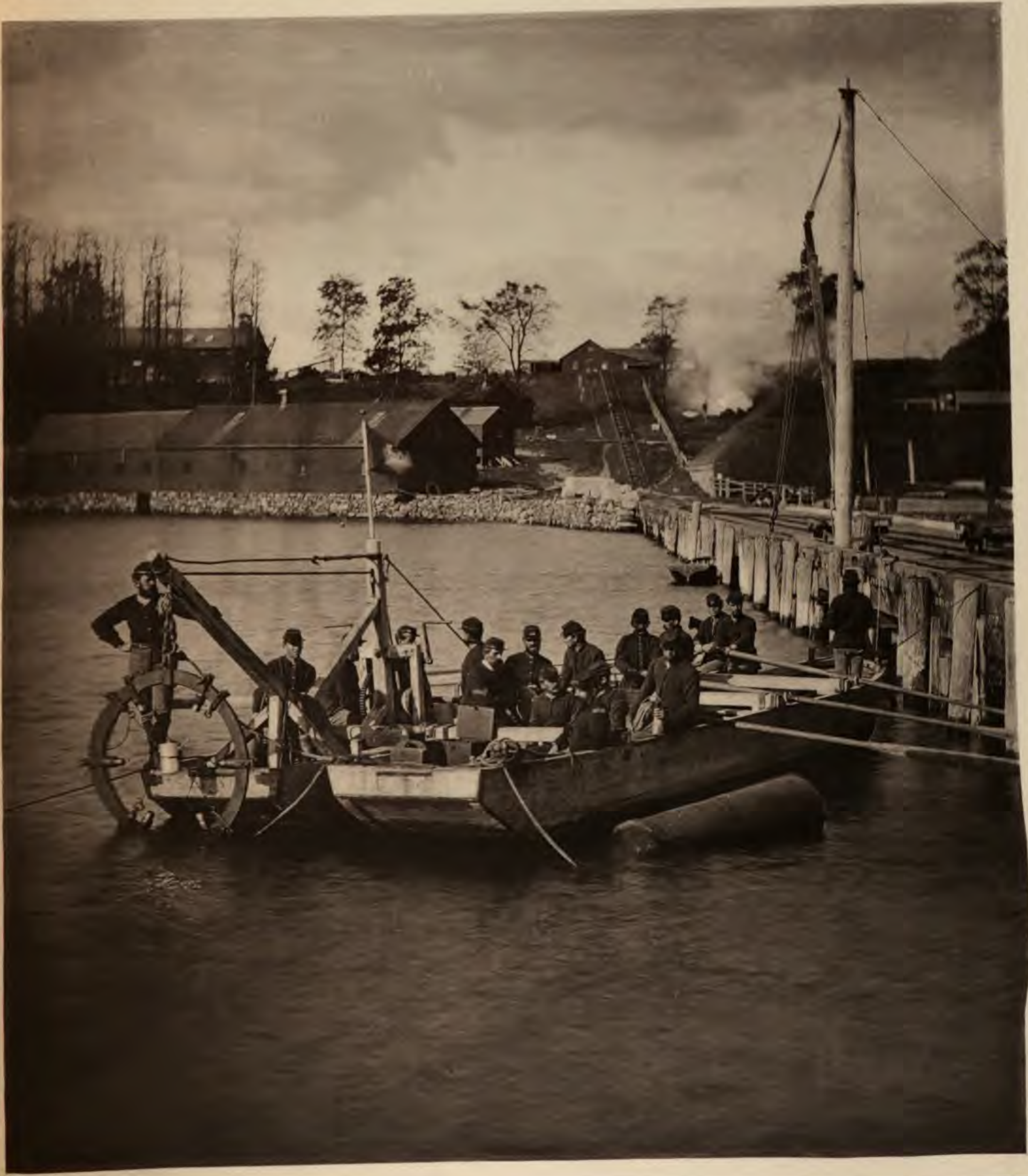
[illegible] the torpedo [illegible] behind it [illegible] to the boom.

[illegible] was the following. The [illegible] and gauges were [illegible] The ring was [illegible]

[illegible] the force [illegible] the whole apparatus into the air. [illegible] Experience, however, soon suggested [illegible] were placed [illegible] of the wire [illegible] This plan could not be used with explosive [illegible] of the smallest charges, [illegible]

[illegible] the weight of the [illegible] In the case of [illegible] explosive [illegible] the maximum which [illegible] safely, [illegible] developing a tendency to upset [illegible] of [illegible]

The [illegible] shown by the [illegible] The former tended to part the wire connecting the [illegible] and buoy, to [illegible] together [illegible] The latter [illegible] of the mooring rope.



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In fact, almost every conceivable accident, except a premature explosion, occurred during this series of trials. Many of them are recorded in the appendices.

Various forms of electrical apparatus were used during the progress of the work. Many shots were successfully exploded with the Smith frictional battery and high tension fuzes. The platinum fuze was often used with the Farmer dynamo-machine, Smith's dynamo-machine, the Laflin & Rand dynamo-machine, and with a voltaic battery. Upon the whole, the Laflin & Rand machine appeared the most convenient; but miss fires were very rare with any of the patterns. In fact, with platinum fuzes properly tested, explosion may be regarded as absolutely certain.

To manœuvre the crate was a much more difficult matter. A schooner of about 55 tons burden was provided, and two booms were so secured to derricks between the masts as to carry the crate slung over the side. The vessel was towed into position, carrying a crew of about thirty soldiers; the crate was lowered until supported by the buoys; the vessel was hauled out of dangerous range; the charge was fired; the crate was raised; the leads were removed and renewed; and another shot was exploded as before. Three shots proved to be a very hard day's work.

Dynamite alone was used with the crate. The charges were gradually increased from 5 to 50 pounds, when the buoys were collapsed by the shock. The instrument was then placed on the bottom, and the effect of a final charge of 100 pounds was successfully measured. As was expected, this explosion destroyed the crate; but not until all desired data had been secured.

Wooden Torpedo Target.—A wooden target was prepared in 1873, with a view to obtain data as to the best method of operating upon an iron target constructed to represent a section from a modern ship of war. Its dimensions were 15 by 15 by 2 feet It was made of two solid layers of squared timber, each stick being 12 by 12 inches in cross-section.

The bottom layer was of oak, the top of spruce; and they crossed each other at right angles, being very strongly held together by 80 through bolts of 1-inch iron. The total weight was 12 tons, giving a free flotation of about 1 ton.

This raft was pierced by eight holes lined with iron pipes, through which iron rods were inserted to hold gauges flush with the bottom. A similar hole was made through the middle, by which the torpedo was slung at any desired depth below the surface.

A charge of 100 pounds of dynamite exploded 60 feet below this massive target, in 120 feet of water, tossed it into the air like a feather, leaving it floating upside down.

To increase its stability, the experiment was then tried of mooring the target in water 30 feet deep; planting four 1,000-pound mushroom anchors 30 feet from its sides, and connecting them by double 6-inch hawsers drawn taut by a tidal lift of 8 feet. This arrangement proved to be successful; and after receiving six severe

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shocks, a charge of 10 pounds of dynamite, hung 10 feet below its bottom, broke it in two pieces, snapping off twelve of the spruce and two of the oak timbers. The details of the experiments will be given hereafter.

Iron Torpedo Target.—The object proposed in preparing this target was to obtain data upon which to base an intelligent estimate of the mean pressure which must be developed by a sub-aqueous explosion, in order to disrupt the bottom of a first-class armored ship of war, constructed upon the double cellular principle. To determine this quantity, absolutely, a series of trials should be made upon a real ship of the kind indicated; and it was only because want of funds rendered such a project impracticable that this substitute was proposed by the Board.

The target was constructed in the spring of 1873, at the Continental Iron Works, Brooklyn, by Mr. T. F. Rowland, who built the first monitor.

The Monarch was selected as the type to be represented; and care was taken to make the target fully equal both in design and workmanship to a corresponding area of her bottom. The materials selected proved to be of high tensile strength and uncommonly malleable and ductile, being greatly superior to the ordinary iron used in ship-building. Great additional strength was given to the structure, as a whole, by the introduction of 17 wrought-iron pipes between the deck and bottom, to facilitate the attachment of the dynamometers and torpedoes. In fine, it is quite certain that conclusions based upon the resistance of this target will be a safe guide in estimating the explosive energy needful to destroy any vessel now afloat.

The target, in general shape a quadrangular box, 20 feet square by 3 feet in depth (internal dimensions), was formed of plate iron closed on all sides, and supported by fore and aft and athwartship framing, dividing the internal space into 25 partial cells, 4 feet long, 4 feet wide, and 3 feet deep. The bottom and sides were formed of plates ¾ inch in thickness, and the top or deck of plates ½ inch in thickness.

The plating corresponded in distribution and fastening with the methods usual in constructing iron ships. The bottom and deck were laid out in strakes with 5-inch laps, in the ordinary "in and out" manner, and double riveted with ⅞-inch rivets. The butts of strakes were covered with suitable straps and double riveted. The plates of the sides and ends were wrought flush, the corners being flanged to right angles, and the butts secured in the same manner as those of the bottom and top. The connecting corner angle-irons were 4 by 4 by ⅝ inches in section; the corner lengths being shaped to right angles by cutting out the surplus iron of the inner leg, and welding the cut surfaces when brought to the correct angles. The butts were properly shifted from the butts of the plating, and efficiently strapped.

The athwartship frames (those crossing the strakes of plating at right angles), were formed of 4 by 4 by ⅝ inch angle-iron, continuous across the bottom, sides, and deck, spaced 4 feet between facing angles. The floor plates were ⅝-inch thick, and extended from side to side, and from bottom to deck, having 4 manholes, 12 by 24 inches, cut through each floor midway between keelson attachments, to afford access through the internal space of the target. The skin and floor plates were efficiently secured to the frames by ⅞-inch rivets.

The fore and aft or longitudinal framing was formed by intercostal plates ⅝-inch thick, spaced to equally divide the target with the four athwartship frames into twenty-five equal spaces. Each connection was made by four plates of triangular form, which left diamond-shaped openings for manholes 22 by 32 inches (greatest dimensions). The intercostals were connected with the skin and the athwartship frames by 4 by 4 by ⅝ inch angle-irons; the butts of the plates being reinforced by straps of sufficient size to receive eight rivets and placed on the reverse side of the connecting angles, so that the butt plates could receive the fastening in wake of the angle-irons—the fastenings thus including plates, angles, and butt straps.

Two circular manholes, 16 inches in diameter, were cut through the deck plating into the corner compartments diagonally opposite each other, and fitted with covers bolted on water-tight. An additional manhole was subsequently cut through the deck more central than the others, entering the compartment next the centre one toward the end of the target; the centre of the hole being amidships in fore and aft line and about 6 feet from the end. This manhole was of the same size as the others and covered by a plate made water-tight, and was enclosed by a circular iron bulwark built up from the deck 3 feet high by 28½ inches diameter. This bulwark was made to enclose the manhole plate and was made water-tight with the deck; affording the means of access to the internal space, in rough weather, by protecting the manhole when the plate was off.

Provision was made for freeing the target of water, from moderate leaks, by fitting connections on the deck at each corner of the target. These were so arranged that by unscrewing covering caps pumps could be inserted, securely locked, and worked effectively by hand.

Four eye-bolts with 6-inch rings were fitted on each side above the water-line for fasts; and subsequently stout straps were added to each corner of the target. These were forged of 1½ by 6½-inch bars, extending on the sides of the target 24 inches. They were secured by six 1½-inch rivets on each side; the two straps being brought together at the corner of the target, and fitted to receive the bolt of a shackle. This shackle was made of 2½-inch round iron, 10 inches in diameter. These attachments were designed for convenience in raising and handling the target when sunk by explosions.

All necessary precautions were observed in making this structure, both by arranging the materials in the most advantageous manner and by thoroughly connecting the various parts. To this end all butts were properly shifted with each other both in plates and connecting angle-irons, and were properly strapped with equivalent sections of material. The rivet holes were fairly laid out, and at suitable distances apart for work joined; and were punched opposite from faying surfaces. The rivets were driven hot, and made to completely fill the holes. All flush work, such as skin plating and deck, were properly countersunk, and the rivets were chipped slightly oval. The external surface was calked and made completely water-tight, no pains being spared to make the target fully equal in workmanship to an equivalent section of the best type of double cellular bottom.

For the purpose of attaching the dynamometers, tubes were inserted from the deck to the bottom, through which rods were thrust, having on their lower ends sockets for receiving the gauges. Suitable fastenings were adopted for holding these rods to their work when the force of the explosion was sufficient to rupture and destroy the target. To accomplish this object the tubes were placed near the inner corner of each of the sixteen compartments adjoining the corners of the target. Another in the center of the middle compartment, was provided for slinging the torpedo. These tubes were made of wrought-iron hydraulic pipe, 4 inches in internal diameter and ½-inch thick, with wrought-iron flanges screwed on the ends. The flanges were riveted to the bottom and deck plating; and the deck and bottom in wake of the internal diameter of the pipe were cut out and calked on the flanges water-tight.

The rods for holding the dynamometers were formed of 3¼-inch round iron and extended to within 2 inches of the bottom of the target. Flat heads were forged on them of sufficient size to prevent them from dropping through the tubes, and bales were connected to the heads for attaching lines and buoys to recover them in case of their becoming detached from the target.

To efficiently secure these rods, so as to resist the force of explosions, the strain had to be removed from the deck and transmitted to the whole structure. To accomplish this, knee brackets formed of 1-inch plates were secured to the contiguous floor plates by clips of angle-iron and were riveted thereto—the knees extending under the deck plating to receive the fastenings of stirrups designed for a transverse holding-down bar. These brackets extended on the floor plates about 14 inches, and under the deck 10 inches, *i. e.*, sufficiently to receive the bolts on each side of the stirrups. As these brackets were placed in the corners of the compartments, near to the union of the floors and keelsons, they distributed the strain upon the rods very efficiently over the strongest part of the structure.

The means employed on deck to secure the rods consisted of forged stirrups bolted through the deck to the knees of the brackets, and of holding-down bars passing over the heads of the rods. The stirrups were forgings 11 inches high by 4¾ inches wide by 4 inches thick, having a base 1 inch thick and 11 inches square. They were slotted out for the holding bar and gibs and keys 7 inches, leaving a section of metal of 2 by 4 inches over the bar and of 1¼ by 4 inches on each side. These sockets were placed as near the openings as practicable (about 21 inches between centres) and in line with the athwartship frames. Each of them was held down by six accurately fitted 1¼-inch bolts passing through the base of the stirrup, the deck plating, and the knee of the bracket below deck.

The holding-down bars were forgings 33 inches long and 5 inches wide by 2 inches thick. They were passed through the slots of the stirrups and were firmly held against the heads of the rods; being set down by gibs and keys at each stirrup —the object being to prevent the rod from having the least up-and-down motion, when acted upon by the explosion. The bales of the rods were of sufficient size to allow the holding-down bars to pass through them, forming convenient attachments for buoy lines.

By these devices, records of the intensity of the force developed by the various explosions were successfully preserved, including those of the one which eventually destroyed the target.

The total weight of the target when ready for an explosion was about 26 tons —placing the deck about 9 inches above the water surface.

To prevent, so far as possible, any general yielding to the shock, four 1,000-pound mushroom anchors were placed opposite each side of the target and connected together by twos over the deck with ⅞-inch chain cables.

A spot having a tenacious clay bottom was selected, and the anchors were placed on the circumference of a circle of which the centre was under the middle of the target. The chains, making an angle of about 45° with the bottom, were hauled taut with blocks and falls; knotted together over the target at low-water; and strained by a tidal rise of about 8 feet. This reduced the deck height to about 3 inches, and enormously increased the resistance to any further upward motion.

Further reference will be made to this question of stability in discussing the experiments.

Torpedo Cases.—The explosives under trial were protected against moisture by a great variety of different kinds of case. The kind used is specified for each shot in the appendices, because this was soon found to exert an important influence upon the energy developed by the explosion.

The first trials of gunpowder were made in cubical wooden boxes of clear pine, varying in thickness from 1 to 3 inches. They were closely jointed, glued, and screwed together, and coated on the outside with roofing cement. Two rope-handles were attached by wooden strips, screwed to opposite sides. The intermediate sides, which were turned outward from the ring when in position for firing, were often prepared to receive gauges buried in the powder. The sockets of these gauges had cylindrical screw-bolts projecting from their bases, which passed through the sides of the box and received ring washers, to which were attached 10-foot lengths of wire rope connected to long 3-inch hemp ropes. Great care was taken to prevent leakage of water round the holes, by close-fitting leather washers compressed into the wood by the screw, and by careful coating with cement. The leading wires were introduced by gimlet holes through the top, afterward closed with soft pine plugs and well coated. The top being screwed on after the charge was inserted, every facility was offered for distributing the fuzes uniformly through the mass. This was usually done by attaching them to a suitable framework of wires nailed inside. The sizes of these cubical boxes were closely computed to contain the charge and gauges, the inside edge being as follows:

8-pound charge, 6 inches in the clear.
25-pound charge, 9¾ inches in the clear.
50-pound charge, 12 inches in the clear.
100-pound charge, 15⅛ inches in the clear.
150-pound charge, 17⅜ inches in the clear.
200-pound charge, 19 inches in the clear.
300-pound charge, 22 inches in the clear.

The later trials with gunpowder were made in oaken kegs, 1 inch thick, strongly bound together with six galvanized iron hoops. They were made to order of three sizes, 8 gallons, 16 gallons, and 24 gallons; and weighed 30, 44, and 64 pounds, respectively. The largest size was sometimes divided into halves by an inside diaphragm, 1 inch thick, placed parallel to the heads.

The small charges of explosive compounds were sometimes confined in glass bottles of various sizes, and in ordinary half-gallon and gallon tin cans; but the usual case consisted of cylindrical tin cans, made to order, provided with good stuffing boxes for introducing the leading-wires, and with a screw-capped hole for loading. The following are the dimensions of these cans, and their approximate capacity for holding dynamite in loose powder:

Fuze can: diameter, $2\frac{6}{8}$ inches; height, 6 inches; capacity, 1 pound.
Can No. 1: diameter, 4 inches; height, 9 inches; capacity, 3 pounds.
Can No. 2: diameter, 6½ inches; height, 9 inches; capacity, 10 pounds.
Can No. 3: diameter, 8 inches; height, 11½ inches; capacity, 20 pounds.
Can No. 4: diameter, 12 inches; height, 13 inches; capacity, 50 pounds.

To strengthen the latter, its heads were braced by a strong inside tube abutting against 4-inch discs; and its middle was stiffened by a strap 1 inch wide, to which two rings were attached for slinging.

Larger charges of explosive compounds were fired in regular torpedo cases; usually made of ¼-inch wrought iron and provided with an excess of capacity to give buoyancy, or of ⅜-inch cast iron filled with the charge.

A few cases designed for special objects will be described when discussing the shots fired in them.

USUAL PHYSICAL PHENOMENA.

Before proceeding to discuss, mathematically, the action of forces developed by explosions under water, a brief abstract will be given of notes relating to what is usually heard, felt, and seen in the vicinity.

The sound is deadened to a surprising degree by water over the charge. A large torpedo, exploded 10 feet or more below the surface, gives a dull muffled report that often is hardly noticed by one intently watching the jet. When the water covering is so thin as to allow the gas instantly to escape into the air, the sound is far more intense. Thus 1 pound of dynamite exploded 3 feet below the surface produces locally a much louder sound than 500 pounds submerged 20 feet.

It is a general characteristic of small and deeply submerged charges of the explosive compounds, and of some quick acting explosive mixtures as well, that at the instant of detonation, before any disturbance of the water at the surface is visible, three sharp sounds are heard resembling raps upon a hard substance. They are of nearly equal intensity; but the interval of time between the first and the second appears to be longer than between the second and the third. That these repetitions are not simply echoes, and that there are really more than three of the impulses, although the ear hardly detects a greater number, have been conclusively proved in several instances where a gauge clutch happened to be out of order. In such cases, several successive indentations in the bottom of the lead have been made by the centre pin as the cylinder moved laterally under the upward jerk given by the buoy

Successive impulses may also be distinctly felt by one standing in a boat near the explosion; and if the hand be placed in the water sensations resembling electric shocks are experienced.

The influence of the shock upon fish is noteworthy. In the immediate vicinity, even of small charges, death appears to be instantaneous. At a greater distance the air bladder is ruptured and, the air ballast escaping into the abdomen, the fish floats upon its back at the surface, although still able to swim with considerable speed At still longer ranges the effect appears to be momentary, simply causing an upward dart into the air. Even 5 pounds of dynamite will produce this effect upon a shoal of manhaden, at distances of several hundred yards—showing that the nervous system of that fish is one of the most sensitive of known gauges.

The jet, as well as the sound, is greatly influenced by the submergence. As small charges afford the best opportunity for studying these phenomena in detail, the following summary of many records upon explosive compounds is given.

A charge of one-fourth of a pound submerged about 35 feet occasions no marked disturbance at the surface, but bubbles of gas continue to rise for many seconds. Fish at 100 yards distance often leap into the air.

A half-pound charge detonated 6 feet below the surface produces a sharp report, and throws up a jet from 20 to 30 feet into the air.

With a 1-pound charge submerged 35 feet, the buoy supporting the ring instantly rises about 2 feet and sinks back out of sight. An upward boiling motion of the water begins about 12 seconds after the explosion. In a strong current this may appear several feet away from the buoy. When the charge is submerged 25 feet the boil rises quicker, and the buoy often reappears with it.

With a 2-pound charge submerged 35 feet the phenomena are similar, the boil appearing in about 9 seconds.

With a 3-pound charge at the same depth, the upward current of water assumes the appearance of a small dome at the surface, appearing about 5 seconds after the explosion. The buoy rises 4 or 5 feet instantly, and sinks back out of sight.

As the charge is increased to 5, 8, and 10 pounds, the depth remaining the same, the greater intensity of action is shown by a quicker motion of the buoy, which is also instantly surrounded by a mist thrown upward from the surface. The dome appears in a second or two, and expands into a small white jet of water 8 or 10 feet high. A boat 50 feet distant from the buoy receives a jar sufficient to lift small articles. Fishes of the herring family dart into the air, as far off as the eye can conveniently distinguish them, those within a radius of a couple of hundred feet being crippled by the concussion.

With explosive mixtures, the effects are similar but less intense. For example, 25 pounds of mortar powder fired 35 feet below the surface, cause a misty shower to rise a foot or two above the water; the buoy shoots up to its full length and falls upon its side; then a white dome rises around it, about 10 feet high. When a strong iron case is used, three sharp raps are heard—which are not often noticed with a wooden case.

When 50 pounds of mortar powder are fired 5 feet below the surface the jet is about 170 feet high; at 16 feet it is about 40 feet high; at 35 feet it is from 20 to 30 feet high; and at 68 feet there is simply a large upward boil around the buoy, occurring several seconds after the explosion. In deep explosions the buoy always shoots upward, and often subsides before any disturbance is seen at the surface.

The effects exhibited by the sub-aqueous explosion of charges, large enough to be practically used for the destruction of shipping, will now receive attention.

The height and form of the jet of water thrown into the air by a given charge, is observed to vary enormously with its submergence; and is probably a delicate index of the combined effect of all the forces transmitted to the surface of the water. It might seem that this feature could be turned to account in studying certain important matters—such, for example, as the effect of varying the strength of case for gunpowder charges; and, indeed, Captain Vandevelde, of Holland, based his system of sub-aqueous measurements upon it. The subject has been very carefully investigated at Willets Point, both instrumentally and by the aid of instantaneous photography, and it has been found that the disturbing action even of very slight currents of air; the varying effects dependent upon the relative position of the sun, the jet, and the observer; the excessive tenuity of the ill-defined cloud of mist which shrouds the main body of water; and, lastly, the rapidity with which the different phases succeed each other, combine to throw too much uncertainty upon the phenomenon to render it a safe basis for important practical conclusions.

Nevertheless, although hardly suited for precise investigation, the phenomena exhibited by large explosions under water are by no means without interest. For example, the fact that a buoy floating vertically over a large torpedo, is always thrown upward in advance of the water, and is carried to a much greater height than any of the spray, is not without significance in studying the relative effect of the energy transmitted from molecule to molecule of the fluid. and of the actual motion of the gas chamber. Again, the fact that fragments of the torpedo, unless acted upon by a strong wind, always fall within a few feet of the explosion, has an important practical bearing upon torpedo warfare.

For a close study of so evanescent a spectacle as is presented by these jets of water, instantaneous photography is of great value; and to Captain Mercur and Captain Quinn, who in succession have had charge of this branch of instruction at the Engineer School of Application at Willets Point, I am indebted for very efficient assistance.

Dimensions of torpedo columns.

Explosive.	Charge.	Depth of water.	Submergence of torpedo.	Column of water.		Remarks.
				Height.	Diameter of base.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Mortar powder ...	70	13	5	300	60	
	70	13	5	330	35	
	80	16	4	290	70	
	100	20	4	400	25	
	100	20	4	400	30	
	100	20	5	270	30	
	100	20	10	80	60	
	225	20	10	190	100	
	280	18	18	110	125	
Dynamite No. 1...	100	10	5	340	35	Strong wind.
	100	17	9	153+	50	Off plate.
	100	21	9	410	45	
	100	21	12	270	60	
	100	40	20	200	70	Under raft 20 feet square.
	100	40	30	130	100	Do.
	200	42	13	75	80	Do.
	200	20	18	121	80	
	200	19	19	81	80	
	200	21	21	70	80	
	200	42	33	110	100	Under raft 20 feet square.

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The foregoing table is based upon measurements of photographs made by these officers, taken as nearly as possible at the instant of maximum development. The last column can be considered only as approximate, but the figures are designed to show the maximum diameter near the water surface, exclusive of mere spray.

Wishing to extend these measurements so as to include more details, I placed six photographic cameras side by side, and so arranged the slides that they could be dropped at will by electricity, the corresponding time also being recorded upon a field chronograph. By this plan the successive phases of an explosion are perfectly registered for future examination. The following table exhibits results obtained in this manner:

Explosive.	Charge.	Depth of water.	Submergence of torpedo.	Time after explosion.	Column of water.	
					Height.	Diameter of base.
	Pounds.	*Feet.*	*Feet.*	*Seconds.*	*Feet.*	*Feet.*
Mortar powder ...	50	13	4	0.1	53	25
				1.3	224	25
				3.0	273	
				3.6	265	
				4.3	276	
Mortar powder ...	50	9	7	0.1	29	30
				1.2	90	
				1.9	66	30
				2.6±	60	
				3.1±	43	
				3.6±	0	
Mortar powder ...	50	9	6	0.1	32	30
				0.9	76	
				1.2	96	
				1.7±	116	
				2.2±	115	
				2.7±	101	
Mortar powder ...	50	9	3	0.1	71	20
				0.9	188	
				1.2	...	
				1.7±	279	
				2.2±	289	
				2.7±	277	
Dynamite No. 1...	500	20	13	0.1	105	100
				0.9	235	80
				1.5	310±	80
				2.6	...	150
				5.4	500±	200
				12.3	0	

The photographs of the last shot recorded in this table (500 pounds of dynamite) exhibit, with great precision, the several normal phases of a sub-aqueous explosion; and as the corresponding times are accurately known, this shot will be adopted as the type for a general description.

The first picture was taken 0.1 of a second after the explosion. The shock had already traversed the 600 feet which separated the camera from the torpedo, and the earth tremor is distinctly shown by a multiplicity of images. The surface of the water around the torpedo, over a diameter of 200 feet, is covered by a misty spray resembling rain, which has been thrown upward from the surface by the shock. Over the torpedo appears a dome of water of which the diameter is about 100 feet and the extreme height about 20 feet. The surface of this dome is of a fleecy texture; and through the top are bursting upward many spear-like jets, which cover a space about 50 feet in diameter and attain in the middle an extreme height of 105 feet. The whole presents an appearance of intense energy which can hardly be conveyed in words.

The second picture was taken 0.9 of a second after the explosion. The tremulous mist has disappeared, and the earth vibration is hardly perceptible. The jet has developed into a massive column, of which the extreme height is about 235 feet. The diameter for 180 feet above the water is about 80 feet; the lower half showing a marked fleecy texture and the upper half incipient jets. Every part indicates a rapid upward motion.

The third picture was taken 1.5 second after the explosion. Everything is still tending upward, the extreme height being about 310 feet. The fleecy texture is now restricted to a height of about 30 feet, all above being blended into a magnificent column 80 feet in diameter, with delicate upward sprays from every part. Under a microscope, the texture for 30 feet above the water is most peculiar, suggesting bunches of wool thrown loosely upon a dense white snow bank. Horizontal tongues in this part of the jet indicate the beginning of a new burst of gas.

The fourth picture, 2.6 seconds after the explosion, was taken to catch the secondary burst of water, which is a characteristic feature of exhibitions of this kind. The column above is still moving upward, with a diameter of about 80 feet. The lower fleecy part has developed horizontally into branching cascades, which cover a diameter of fully 150 feet and form a fitting pedestal to the grand column.

The fifth picture was taken, 5.4 seconds after the explosion, to catch the appearance of the column when at its maximum development. The base has now spread out to a diameter of 200 feet, but there is no longer any exhibition of intense forces in action. The vast cloud-like column is relieved against the sky, showing a general diameter of about 100 feet and an extreme height of about 500 feet.

The sixth picture was taken at 12.3 seconds after the explosion. The mass of water has already settled back into the enlarging circle which marks the place of the disturbance, and only a dissolving mist remains suspended in the air.

As already mentioned, the shock of this torpedo caused so strong an earth tremor as to render it impossible to obtain a sharply-defined picture at the instant of the explosion. At a distance of half a mile the effect resembled a slight earthquake, causing a severe jar to be felt, windows to rattle, etc. These earth tremors are usual with large torpedo explosions.

The rate at which such tremors traverse the earth's surface has received attention

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in connection with these investigations. The results have been already published,* and only a brief summary will therefore be given here.

The observations, which included the great explosion at Hallett's Point, were made under my direction by officers of the Battalion of Engineers. Mercury seismometers of two types were used; that marked A having a magnifying power of 6, and that marked B of 12. The instant of explosion and the time of the arrival of the tremor were electrically recorded on the same moving paper with precision. The following table exhibits the results:

Number of observations.	Date.	Observer.	Cause of shock.	Distance to station.	Type of seismometer.	Tremor of mercury.		Velocity of transmission.
						Arrived in—	Lasted for—	
				Miles.		*Seconds.*	*Seconds.*	*Ft. per second.*
1	Aug, 18, 1876	Captain Livermore	200 pounds dynamite	5. ±	B.	5. ±	......	5,280±
2	Sept. 24, 1876	Lieutenant Young	Hallett's Point explosion	5.134	A.	7. ±	63.0±	3,873±
3	....do	Lieutenant Griffin	......do	8.330	B.	5.3	72.3	8,300
4	....do	Lieutenant Kingman	......do	9.333	A.	10.9	23.5	4,521
5	.. do	Lieutenant Leach	......do	12.769	B.	12.7	19.0	5,309
6	Oct. 10, 1876	Lieutenant Kingman	70 pounds powder	1.360	A.	5.8	Inst.	1,240
7	Sept. 6, 1877	......do	400 pounds dynamite	1.169	A.	1.8	7.8	3,428
8	.. do	Lieutenant Leach	......do	1.169	B.	0.7	17.8	8,814
9	Sept. 12, 1877	Lieutenant Griffin	200 pounds dynamite	1.340	A.	1.05	8.8	6,730
10	... do	Lieutenant Leach	......do	1.340	B.	0.81	17.1	8,730
11	... do	Lieutenant Griffin	70 pounds powder	1.340	A.	1.27	4.8	5,559
12	....do	Lieutenant Leach	......do	1.340	B.	0.84	15.1	8,415

A discussion of these data showed that type A was defective from insufficient optical power; and the results obtained with it are only useful as exhibiting the rate of advance of waves having more intensity than belongs to the leading tremor.

The following general conclusions were suggested by the limited investigation which could be given to the subject: 1st. A high magnifying power of telescope is essential in seismometric observations. 2d. The more violent the initial shock the higher is the velocity of transmission. 3d. This velocity diminishes as the general wave advances. 4th. The movements of the earth's crust are complex, consisting of many short waves first increasing and then decreasing in amplitude; and, with a detonating explosive, the interval between the first wave and the maximum wave, at any station, is shorter than with a slow-burning explosive. 5th. For the drift formation of which Long Island is composed, the following are the normal rates of advance of the leading tremors induced by an explosion:

200 pounds of dynamite give for 1 mile, 8,730 feet per second.
200 pounds of dynamite give for 5 miles, 5,280 feet per second
50,000 pounds of dynamite give for 8 miles, 8,300 feet per second.
50,000 pounds of dynamite give for 13½ miles, 5,300 feet per second.

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* See No. XL, Printed Papers of the Essayons Club of the Corps of Engineers; also the American Journal of Science and Arts, Vol. XV, March, 1878.

GENERAL MATHEMATICAL ANALYSIS.

An extensive series of measurements with the apparatus already described was so conducted as to determine, for the unit of surface exposed to the shock, both the available kinetic energy developed by sub-aqueous explosions of various kinds, and the mean intensity of action which they severally would have exerted upon discs of copper, acting through the medium of a Rodman indenting-tool. The method adopted for generalizing these data is now to be considered.

In a theoretical consideration of the subject, the available kinetic energy per unit of surface possesses decided advantages over the corresponding intensity of action; while the discovery of the mathematical law connecting the two, stated in discussing the scale, renders it easy to translate the former into the latter, the best quantity for a general discussion of the problem under consideration.

The following definitions of the various symbols which enter the formulæ will be given here for convenience of reference:

W = That part of the potential energy of the explosive which is available for transformation into mechanical work by a sub-aqueous explosion. It is expressed in foot-pounds per square inch of surface exposed to the shock.

P = The corresponding mean pressure which would be transmitted to a disc of copper by a Rodman indenting-tool, expressed in pounds per square inch of surface exposed to the shock.

C = The weight of the explosive in pounds.

D = The distance in feet from the centre of the explosion to the surface exposed to the shock.

S = The submergence of the centre of the charge below the water surface, expressed in feet.

N = The number of fuzes in the charge, which are assumed to be distributed uniformly throughout its entire mass.

R = The radius of a sphere which equals in volume the quantity of the explosive allotted to each fuze For gunpowder, it may be computed from the following formula, which is based upon the assumption that one pound contains 30 cubic inches. $R = \sqrt[3]{\frac{3 \times 30\,C}{4\,\pi\,N}} = \sqrt[3]{7.161\frac{C}{N}}$. With two fuzes attached to 12 feet of Gomez lightning fuze, coiled in the torpedo, experiment showed that $R = \frac{C}{28}$

ϑ = The angle with the vertical passing through the centre of the charge, made by a line drawn from that point to the surface exposed to the shock, reckoned from the nadir and expressed in degrees.

K, A, B, E = Constants to be determined by experiment.

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There are other variables which might be expected to enter a general formula for a sub-aqueous explosion, but which have not appeared to exert a sensible influence in the practical trials made at Willets Point. Such, for example, is the total depth of water at the place of the explosion. With a hard bottom, it is probable that when S nearly equals this depth, *i. e.*, when the charge rests near the bottom, the upward pressure is re-enforced by elastic reaction. The bottom at Willets Point being soft mud, no such effect has been detected either with explosive compounds or mixtures; and the quantity is therefore ignored in the text, although given for each shot in the appendices. Again, the nature of the fuze priming might be expected to exert a decided effect upon the force developed by an explosive mixture. This point has been carefully investigated; and the results with gunpowder appear to be sensibly the same whether this priming consists of fulminating mercury, safety compound (potassium chlorate and crude gamboge), or gunpowder.

In framing a general formula for the available energy developed by a sub-aqueous explosion certain recognized principles are applicable, such as the following:

With detonating compounds, where the time occupied by the chemical reaction is so short that none of the explosive is lost, it may fairly be assumed that the available energy developed is proportional to the charge. With explosive mixtures much of the material is thrown into the water unburned; unless, what in practice is never attained, the torpedo case be so exceptionally strong as to require the full tension of the gas to rupture it. Some function of the charge, of which the simplest form may be assumed to be C^x, must therefore be placed in the numerator of the second member of the general expression for W.

In a perfectly incompressible fluid, the total energy transmitted through it from molecule to molecule must be equal upon every spherical surface enveloping the explosive as a centre. In other words, the energy at any point must be inversely proportional to the square of the distance of that point from the centre of the charge Water, however, is not a perfectly incompressible fluid.

Moreover, a formula framed upon the supposition that the energy varies only as a power of D would indicate an infinite energy for zero distance.

For these reasons the function representing the distance, in the most general case, should be placed under the form $(D + A)^q$ in which A is a small constant, and in which the exponent must always be nearly equal to two. This function enters the formula for W, of course, in the denominator.

The effect of increasing the submergence of the charge is to increase the pressure of the surrounding fluid, and hence to develop greater resistance to the formation of the gas chamber at the instant of explosion. In a practical formula, like that under consideration, variations in the condition of the atmosphere may be ignored. A function of the form S^y placed in the numerator of the second member of the expression for W, will therefore fulfil the needful conditions.

Remembering that when $R = 0$, C can only be zero, a little consideration will show that a function of the form R^z placed in the denominator of the second member of the expression for W, will fulfil the needful conditions for that quantity.

The probable action of the forces developed by a sub-aqueous explosion, has already been considered on page 17, where the reasons are stated for anticipating that the normal line of maximum intensity will be directed upward; and of minimum intensity, downward. A function of the form $(\vartheta + E)^t$ in the numerator of the value for W, will fulfil these conditions.

From the foregoing considerations, it appears that the value of W for the most general case of a sub-aqueous explosion may be expressed as follows, K being a constant dependent upon the nature of the particular explosive under trial:

$$W = \frac{K\,(\vartheta + E)^t\, S^y\, C^x}{(D + A)^q\, R^z} \tag{5}$$

Having a sufficient number of good observations intelligently varied in details, it is easy to determine the values of the unknown quantities in this equation by a judicious combination of the graphical method with that by least squares; and thus to frame a working formula, the value of which will be decided by the accordance between its indications and the measurements.

Having by this process deduced a satisfactory expression for W, it remains to indicate the mode of deriving from it an expression for P

As already intimated, this will be done by dividing W by the expression for the indentations made by Rodman's cutter in his discs of copper, when subjected to blows of the pendulum of the same kinetic energy which determined the shortenings of the standard $\frac{75}{100}$ lead, viz:

$$I = 0.002156\, W^{\frac{1}{3}} \tag{4}$$

Remembering that the No. 1 gauge, of which the piston-head has an area of one-tenth of an inch, was adopted as the standard, while W denotes the energy per square inch of surface exposed, we have:

$$\frac{P}{10} = \frac{0.1\, W}{0.002156\, (0.1\, W)^{\frac{1}{3}}}$$

Hence:

$$P = \frac{(0.1\, W)^{\frac{2}{3}}}{0.0002156} \tag{6}$$

It only remains to substitute for W in this equation the value derived from equation (5), and to reduce the resulting expression for P to a convenient form for practical use.

A comprehensive series of experiments directed to determine the numerical values of the constants in equation (5), was made with the apparatus already described. All

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the principal explosive agents were studied in this manner; but, to economize labor, advantage was taken of the broad distinction between them based upon their chemical constitution as compounds and mixtures. As a rule, the former may be easily detonated, while the latter explode by rapid combustion. Under any circumstances, this difference is fundamental; but it is particularly so with operations under water, where the strength of the case is usually insufficient to prevent rupture before the full volume of gas theoretically available from an explosive mixture, can be generated. In such cases an unknown portion of the charge may be thrown into the water unburned, thus modifying the result in a manner not easy to foresee.

To reduce the expense and labor as much as possible, the general project contemplated a full study of only one typical explosive of each class—trusting that a few shots carefully planned would develop the peculiarities of others of the same general nature. Gunpowder was selected as a fair type for chemical mixtures, and dynamite No. 1 for chemical compounds. The data for each class will now be considered in detail.

ANALYSIS OF THE DATA FOR EXPLOSIVE MIXTURES.

Mortar powder was selected as the most convenient variety of this class of explosives; and 65 unexceptionable shots were fired, under the conditions needful to determine the numerical values of the several unknown quantities in the general formulæ given above.

Mortar Powder.—In these experiments the charges varied from 25 to 300 pounds; the submergence, from 6 to 68 feet; and R, from 3 to 11 inches. All the details of the several shots will be found in Appendix A.

Being convinced, at the outset, that the best explosive for the torpedo service would be found among explosive compounds, the study of explosive mixtures was mainly undertaken to throw light upon certain peculiar features of this class; and no attempt was made to minutely investigate the function of the distance—which, offering great difficulties with the large charges employed, could be studied more accurately with explosive compounds. Trials were therefore restricted to the 3-foot, 4-foot, and 5-foot rings—giving for D a range varying only from 1.12 to 2.12 feet. For this reason, the exponent of its function was assumed to be 2; a value which, from the general principle of the conservation of energy, must very closely approximate to the truth.

The study of the function $(\vartheta + E)^t$ was simplified by the symmetrical arrangement of the gauges, which rendered it admissible, in the first analysis of the data, to assume it to be unity for *the mean* of the six ring gauges. Since two of these gauges were 60° above, two 60° below, and two in the same horizontal plane as the charge, this assumption, in effect, restricts the indications of the resulting formula to that plane. The subject will be considered more fully hereafter.

A careful study, by the graphical method, showed that A could differ but slightly from unity, and that value was accordingly adopted.

The general formula, equation (5), was then placed under the following form, suited for the application of the method of least squares.

$$\log. W + 2 \log. (D + 1) = \log. K + y \log. S + x \log. C - z \log. R$$

From the 65 equations of condition the following 4 normal equations were derived:

$$\begin{aligned}
82.7427 &= 45.1013 \log. K + 67.7481\, y + 86.6107\, x - 33.0122\, z \\
119.5396 &= 65.0000 \log. K + 97.2164\, y + 124.4341\, x - 45.1013\, z \\
178.9474 &= 97\ 2164 \log, K + 148.2486\, y + 186.1731\, x - 67.7481\, z \\
235.8017 &= 124.4341 \log. K + 186.1731\, y + 241.7585\, x - 86.6107\, z
\end{aligned}$$

Whence:

$$\begin{aligned}
K &= 0.025 \\
y &= 0.026 \\
x &= 1.934 \\
z &= 0.460
\end{aligned}$$

Substituting these values in equation (5), it becomes for the horizontal plane containing the charge:

$$W = \frac{0.025\, S^{0.026}\ C^{1.934}}{(D + 1)^2\, R^{0.46}} \tag{7}$$

To pass from this energy formula to the corresponding expression for the mean pressure developed by the explosion, combine equations (6) and (7); and, by slightly modifying the numerical values of the constants, reduce the resulting equation to a convenient working form, viz:

$$P = \left(\frac{790\, S^{\frac{1}{40}}\ C^{1.94}}{(D + 1)^2 \sqrt{R}}\right)^{\frac{2}{3}} \tag{8}$$

The following table exhibits, in a more compact form than Appendix A, the data from which the constants in these formulæ have been derived, and also the degree of accordance between their indications and the observations. It is considered that the latter is sufficiently close to warrant their adoption. The possibility of leakage must be remembered, and to this cause may fairly be attributed some of the discrepancies; the explanation of others will be given hereafter.

The following abbreviations are used in the sixth column of the table: F. M., fulminating mercury; S. C., safety compound; Gun., gunpowder; F. M & G., fulminating mercury primings and 12 feet of Gomez fuze.

Summary of mortar powder experiments.

No. of shot.	Charge.		Distance to gauge. (D)	Fuzes.			Mean pressure per square inch. (P)			Remarks.
	Weight. (C)	Submergence. (S)		No.	Priming.	Radius. (R)	Observed.	Comp.	Difference.	
	Pounds.	*Feet.*	*Feet.*			*Inches.*	*Pounds.*	*Pounds.*	*Pounds.*	
171	25	35	1.12	1	F. M......	5.64	1,294	1,203	+ 91	
172	25	35	1.12	2	...do	4.47	1,346	1,300	+ 46	
173	25	35	1.12	2	...do	4.47	1,237		− 63	
174	25	35	1.12	2	...do	4.47	1,283		− 17	
176	25	35	1.12	2	...do	4.47	1,244		− 56	
175	25	35	1.12	2	...do	4.47	5,250	......	....	Cast iron case.
1	50	30	1.12	10	S. C.......	3.29	2,941	3,523	− 582	
49	50	32	1.12	1	F. M......	7.10	4,502	2,732	+ 1,770	
159	50	35	1.12	1	Gun	7.10	2,230		− 502	
160	50	35	1.12	1	...do	7.10	3,249		+ 517	
45	50	32	1.12	2	F. M. & G.	1.79	4,551	3,708	+ 843	
161	50	35	1.12	9	F. M......	3.41	2,303	3,490	− 1,187	
46	50	32	1.12	9	...do	3.41	5,594		+ 2,104	
70	50	33	1.62	1	S. C.......	7.10	1,364	2,058	− 694	
71	50	33	1.62	1	Gun	7.10	1,556		− 502	
136	50	35	1.62	1	...do	7.10	1,924		- 134	
138	50	35	1.62	1	...do	7.10	1,252	2,058	− 806	
139	50	35	1.62	1	...do	7.10	800		− 1,258	Doubtful.
140	50	35	1.62	1	...do	7.10	1,628		− 430	
10	50	31	2.12	10	F. M......	3.29	2,025	2,105	− 80	
18	50	31	2.12	10	...do	3.29	2,460		+ 355	
21	50	20	2.12	10	...do	3.29	1,418	2,088	− 670	
24	50	68	2.12	10	...do	3.29	3,542	2,132	+ 1,410	
28	50	33	2.12	10	...do	3.29	3,011	2,107	+ 904	
29	50	21	2.12	10	...do	3.29	2,878	2,092	+ 786	
51	100	6	1.12	9	...do	4.31	11,871	7,670	+ 4,201*	* Ring fell on bottom.
56	100	6	1.12	9	...do	4.31	6,227		− 1,443	
85	100	6	1.12	9	...do	4.31	8,858		+ 1,188	
3	100	15	1.12	20	S. C.......	3.29	9,876	8,522	+ 1,354	
4	100	45	1.12	20	...do	3.29	7,734	8,680	− 946	
52	100	32	1.12	1	F. M......	8.95	8,140	6,177	+ 1,963	
162	100	35	1.12	1	Gun	8.95	6,842		+ 665	
42	100	32	1.12	2+	F. M. & G.	3.57	9,054	8,395	+ 659	
84	100	63	1.12	3	F. M......	6.20	7,481	7,068	+ 413	
47	100	32	1.12	9	...do	4.31	11,344	7,889	+ 3,455	
87	100	33	1.12	9	...do	4.31	7,460		− 429	
89	100	35	1.12	9	...do	4.31	6,532		− 1,357	
82	100	33	1.12	9	...do	4.31	9,907		+ 2,018	
34	100	33	1.62	1	...do	8.95	3,151	4,663	− 1,512	Doubtful.
30	100	33	1.62	1	...do	8.95	6,144		+ 1,481	
36	100	33	1.62	1	S. C	8.95	6,425		+ 1,762	
188	100	35	1.62	1	F. M......	8.95	4,160		− 503	
370	100	35	1.62	1	...do	8.95	4,163		− 500	
187	100	35	1.62	1	...do	8.95	7,848		+ 3,185	
38	100	33	1.62	1	...do	8.95	6,921		+ 2,258	
39	100	33	1.62	1	S. C.......	8.95	6,559		+ 1,893	
60	100	33	1.62	1	Gun	8.95	6,643		+ 1,980	
129	100	35	1.62	1	...do	8.95	2,996		− 1,667	Doubtful.
31	100	33	1.62	7	F. M......	4.68	5,256	5,788	− 532	
40	100	33	1.62	7	...do	4.68	8,302		+ 2,414	
32	100	33	1.62	9	...do	4.31	7,102	5,948	+ 1,154	

Summary of mortar-powder experiments—Continued.

No. of shot.	Charge.		Distance to gauge. (D)	Fuzes.			Mean pressure per square inch. (P)			Remarks.
	Weight. (C)	Submergence. (S)		No.	Priming.	Radius. (R)	Observed.	Comp.	Difference.	
	Pounds.	*Feet.*	*Feet.*			*Inches.*	*Pounds.*	*Pounds.*	*Pounds.*	
125	100	6	1.62	9	F. M......	4.31	4,883	5,783	— 900	
35	100	33	1.62	9	...do	4.31	8,298	5,948	+ 2,350	
37	100	33	1.62	25	...do	3.06	6,595	6,668	— 78	
33	100	33	1.62	25	...do	3.06	10,781		+ 4,113	
19	100	31	2.12	10	.. do	4.15	4,079	4,768	— 689	
9	100	31	2.12	20	S. C.......	3.29	2,625	5,151	— 2,526	
12	100	31	2.12	20	...do	3.29	5,378	5,151	+ 227	
25	100	68	2.12	20	F. M......	3.29	6,232	5,219	+ 1,013	
26	100	68	2.12	20	...do	3.29	5,388		+ 169	
27	100	33	2.12	20	...do	3.29	6,480	5,156	+ 1,324	
109	150	35	1.62	9	...do	4.92	9,644	9,602	+ 42	
128	150	35	1.62	9	...do	4.92	7,996		— 1,606	
110	150	35	1.62	2+	F. M. & G.	5.36	9,213	9,362	— 149	
127	150	35	1.62	2+	...do	5.36	8,201		— 1,161	
11	150	31	2.12	30	F. M......	3.29	6,407	8,708	— 2,301	
15	150	31	2.12	30	S. C	3.29	8,970		+ 262	
22	150	31	2.12	20	F. M......	3.77	8,346	8,322	+ 24	
65	200	43	1.62	1	Gun	11.27	13,795	10,632	+ 3,163	
59	200	43	1.62	9	F. M	5.42	13,650	13,567	+ 83	
108	200	45	1.62	9	...do	5.42	10,699	13,580	— 2,881	
118	200	45	1.62	9	S. C.......	5.42	12,033		— 1,547	
105	200	45	1.62	2+	F. M. & G.	7.14	12,402	12,387	+ 15	
126	200	45	1.62	2+	.. do	7.14	14,613		+ 2,226	
180	300	55	2.12	9	....do	6.20	13,221	17,450	— 4,229	See Appendix A.
Arithmetical sum..							452,577	430,236	90,112	

Thus far, as already explained, the analysis has been based upon conditions which restrict the resulting formulæ to the horizontal plane containing the charge. The next step is to study the effect of varying the vertical angular direction of the body receiving the shock.

It might appear that the indications of the buoy and shackle gauges would furnish every needed facility for this discussion, as well as for testing the effect of great variations in distance; but, as will hereafter be proved, the motion of these gauges away from the centre of explosion, totally changes their indications and renders them worthless for these objects. The only resource, therefore, is to study the individual ring gauges; of which, it will be remembered, Nos. 1 and 2 are 60° above, and Nos. 5 and 6, 60° below, the horizontal plane containing the charge and Nos. 3 and 4.

The following table exhibits a general summary of observations with explosive mixtures, the details of which will be found in Appendix A. Every shot for which six perfect records were secured is included.

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Analysis of the vertical angular function.

Explosives.	No. of shots.	Mean pressures per square inch, by gauges.					
		No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Mortar powder	66	5, 851	6, 116	5, 977	6, 408	5, 601	5, 883
Musket powder	10	6, 479	6, 377	7, 208	7, 004	7, 357	7, 486
Cannon powder	3	949	954	1, 003	862	998	566
Mammoth powder	3	458	430	330	458	488	599
Orange lightning powder	2	13, 022	17, 885	14, 660	11, 779	11, 634	13, 041
Oliver powder	1	369	304	304	146	304	232
Safety compound, O. P. C	15	13, 233	13, 551	12, 753	13, 223	12, 609	13, 188
Grand means	100	6, 791	7, 109	6, 915	7, 190	6, 604	6, 874

This table proves conclusively that, with explosive mixtures, there is no well-marked difference in the initial intensities of action in different directions in a vertical plane passing through the centre of explosion, when the number of observations is sufficiently multiplied to eliminate the disturbing effect of anomalies.

Nevertheless, a study in detail of the data which makes up this table will reveal the fact that this general law, deduced from the grand mean, does not apply to individual shots—which usually indicate a decided maximum intensity in *some* direction. Hence the general law is due to a wide and apparently anomalous variation in this line of direction. In other words, there is usually a marked burst of gas, but it is as likely to occur in one direction as another.

Shot No. 180 furnishes a good example to illustrate this tendency. The charge was 300 pounds of mortar powder, exploded in the 5-foot ring submerged 55 feet below the surface, in water 108 feet deep. There were nine fuzes well distributed through the mass. The following figures exhibit the observed mean pressures in pounds per square inch, arranged as nearly in their true relative positions as the types will permit. The plane of the paper represents the vertical plane containing the ring, the top of the page being directed toward the water surface.

No. 1. 12,979 25,072 **No. 2.**

No. 3. 10,118 **Torpedo.** 16,118 **No. 4.**

No. 5. 6,863 8,175 **No. 6.**

Evidently, in this shot the box first burst open near gauge No. 2; and the supply of gas, sustained for an instant by the combustion within, poured out as from the muzzle of a gun, chiefly in that direction. Toward No. 5 a corresponding minimum is apparent. The *duration* of this directive action was, of course, excessively short; for the box was broken into *many* well-compressed fragments, although made of 3-inch hemlock.

In fine, then, it appears that, with explosive mixtures, the direction of the line of maximum initial intensity of action is chiefly determined by the accidental yielding of the case; and hence that *the above formulæ may be considered general* in respect to direction. It will be seen, hereafter, that a very different and well marked law governs explosive compounds; the detonation of which usually subjects the case to so sudden and enormous a strain as to literally pulverize it.

It may be remarked that this peculiar action of explosive mixtures, in respect to direction, very probably explains some of the discrepancies of the mortar-powder table given above. Unless the case should first open in the plane of the ring the maximum impulse would escape measurement, and the resulting mean energy would be too small.

In order to compare mortar powder with certain other explosive mixtures, for use in sub-aqueous explosions, a few shots were fired with mammoth, cannon, musket, and fine sporting rifle powder; with a slow burning powder made by replacing a part of the carbon by uncarbonized peat; and with the safety compound of the Oriental Powder Company, which consists of an intimate mixture of potassium chlorate and crude gamboge.

As these mixtures all explode by the ignition and combustion of the individual grains, they may be assumed to resemble mortar powder sufficiently to be governed approximately by the laws indicated in equation (8). If so, it is only needful to find new values for the numerical constant. This has been done by computing for each shot the value of P by equation (8), and then dividing the observed P by this quantity. The mean of all such ratios, raised to the three-half power, is then multiplied by the constant 790 of the mortar-powder formula; and the product is adopted as the value of that constant for the particular explosive in question. The results will now be noticed in turn.

Mammoth Powder.—This explosive was only tested to make the list complete; for its combustion being exceedingly slow, it is certain that the grains must be thrown into the water before they have time to burn. That this is the case was evident from the appearance of the jets, which were only about 15 feet high, and discolored by grains of powder. The boxes were broken into large pieces, showing little intensity of action. The following table exhibits the details of the experiments.

Summary of mammoth-powder experiments.

No. of shot.	Charge.		Distance to gauge. (D)	Fuzes.			Mean pressure per square inch. (P)			Remarks.
	Weight. (C)	Submergence. (S)		No.	Priming.	Radius. (R)	Observed.	Comp.	Difference.	
	Pounds.	*Feet.*	*Feet.*			*Inches.*	*Pounds.*	*Pounds.*	*Pounds.*	
111	100	35	1.62	9	F. M	4.30	759	495	—264	
113	100	35	1.62	1	Gun	8.95	315	388	+ 73	
367	100	35	1.62	1	F. M	8.95	324		+ 64	

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The formula deduced for mammoth powder by the process indicated above is the following; and it would appear from the table that the advantage of numerous points of ignition is greater than with mortar powder, a result naturally to be expected:

$$P=\left(\frac{19\,S^{\frac{1}{40}}\,C^{1.94}}{(D+1)^2\,\sqrt{R}}\right)^{\frac{2}{3}} \tag{9}$$

The ratio derived from those experiments for the relative strength of mammoth to mortar powder, in sub-aqueous explosions, is 0.083; while the reciprocal of the like ratio between the sizes of the grains is 0.107, showing that the strength, for use under water, is nearly inversely proportional to the size of the grains.

Oliver Powder.—But one shot, No. 369, was fired with this explosive, as it was known to be a slow burning grade, designed specially to give a sustained force with little smoke in rock blasting. The composition and process of manufacture are novel. The distinguishing peculiarity is the substitution of uncarbonized peat for charcoal, in varying proportions. The charge was composed of 75 parts of nitre, 10 of sulphur, 10 of charcoal, and 5 of uncarbonized peat, the whole weighing 72.5 pounds. The powder was unglazed, but free from dust, and of a clear brown color. The size of the grains varied, the charge being an equal mixture of two kinds, one cannon and the other musket.

The shot was fired in the 4-foot ring, 35 feet below the surface, in 90 feet of water, being ignited by one fulminating fuze. The case was an ordinary beer-keg. The jet was small and discolored with unburned grains. The distance from the centre of the charge to the gauges was 1.62 feet. The measured energy per square inch of surface exposed (mean of six gauges) was 8.04 foot-pounds; and the mean pressure, 276 pounds. The ratio of strength to that of mortar powder is from these figures 0.086, giving the formula:

$$P=\left(\frac{20\,S^{\frac{1}{40}}\,C^{1.94}}{(D+1)^2\,\sqrt{R}}\right)^{\frac{2}{3}} \tag{10}$$

The introduction of the peat and the peculiarities of manufacture have evidently so retarded combustion as to render this explosive sensibly the equivalent of mammoth powder when fired under water. Hence, although quite unsuited for torpedoes, a trial in cannon might develop valuable properties.

Cannon Powder.—The trials with this grade, also, were merely formal; and the following table exhibits the results. The jets all indicated much more intensity of action than was developed by mammoth powder; and shot No. 114 threw the whole apparatus into the air, with the column of water.

Summary of cannon-powder experiments.

No. of shot.	Charge.		Distance to gauge. (D)	Fuzes.			Mean pressure per square inch. (P)			Remarks.
	Weight. (C)	Submergence. (S)		No.	Priming.	Radius. (R)	Observed.	Comp.	Difference.	
	Pounds.	*Feet.*	*Feet.*			*Inches.*	*Pounds.*	*Pounds.*	*Pounds.*	
112	100	25	1.62	9	F. M	4.30	882	1,055	+ 173	
114	100	35	1.62	1	Gun	8.95	773	826	− 53	
368	100	35	1.62	1	F. M	8.95	1,012		+ 186	

The formula deduced from these observations, which it will be noticed show marked variations between different shots, is:

(11) $$P = \left(\frac{59\ S^{\frac{1}{40}}\ C^{1.94}}{(D+1)^2\ \sqrt{R}} \right)^{\frac{2}{3}}$$

The ratio indicated by these experiments for the relative strength of cannon and mortar powder in sub-aqueous explosions is 0.177, the reciprocal of the like ratio between the sizes of grain being 0.27. This is the largest difference between these ratios noted for the different grades of gunpowder.

Musket Powder.—Although this grade is better adapted to the needs of the torpedo service than mortar powder, the difference is not so great as to call for many comparative trials. The following table exhibits the results obtained:

Summary of musket-powder experiments.

No. of shot.	Charge.		Distance to gauge. (D)	Fuzes.			Mean pressure per square inch. (P)			Remarks.
	Weight. (C)	Submergence. (S)		No.	Priming.	Radius. (R)	Observed.	Comp.	Difference.	
	Pounds.	*Feet.*	*Feet.*			*Inches.*	*Pounds.*	*Pounds.*	*Pounds.*	
470	48	33	1.12	1	F. M	7.00	5,364	4,102	− 1,262	In can No. 4.
471	48	33	1.12	1	....do	7.00	5,598		− 1,496	Do.
223	100	35	1.62	2	S. C	7.10	5,073	7,915	+ 2,842	In keg.
387	100	35	1.62	1	F. M	8.95	4,347	7,328	+ 2,981	Do.
189	100	35	1.62	1	.. do	8.95	6,899		+ 429	Do.
190	100	35	1.62	1	....do	8.95	7,981		− 653	Do.

A discussion of these shots, by the usual methods, gives for the equation of musket powder:

(12) $$P = \left(\frac{1554\ S^{\frac{1}{40}}\ C^{1.94}}{(D+1)^2\ \sqrt{R}} \right)^{\frac{2}{3}}$$

The deduced ratio for relative strength, as compared with mortar powder, is 1.57, the reciprocal of that between the sizes of grain being 1 80.

Sporting Powder.—If it should ever be necessary to employ gunpowder in a torpedo, it is certain, upon general principles, that the quicker the variety the better will be the result. To determine the maximum intensity of action to be expected from this

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explosive, some Orange Lightning powder was procured from the Laflin & Rand Powder Company as a fair sample of the best quality of sporting powder. It was supplied in 25-pound kegs, at a cost of 70 cents per pound, being sold in flasks at $1. Three grades were purchased—No. 2, No. 3, and No. 5—the first named being slightly the finer. The standard initial velocity of No. 3, fired in a musket, is 1,700 feet per second. It probably could have been purchased in bulk for 45 cents per pound mortar powder costing 20 cents.

Two charges were exploded, each being mixtures of equal parts of two grades. The following table exhibits the results:

Summary of sporting-powder experiments.

No. of shot.	Charge.		Distance to gauge. (D)	Fuses.			Mean pressure per square inch. (P)			Remarks.
	Weight. (C)	Submergence. (S)		No.	Priming.	Radius. (R)	Observed.	Comp.	Difference.	
	Pounds.	*Feet.*	*Feet.*			*Inches.*	*Pounds.*	*Pounds.*	*Pounds.*	
170	100	35	1.62	9	F. M..........	4.30	13,729	15,556	+ 1,827	Numbers 3 and 5.
169	100	35	1.62	1	Gun	8.95	13,611	12,183	− 1,428	Numbers 2 and 5.

Discussed as above indicated, these results give the following formula for sporting powder:

$$P = \left(\frac{3331 \ S^{\frac{1}{40}} \ C^{1.94}}{(D+1)^2 \sqrt{R}} \right)^{\frac{2}{3}} \qquad (13)$$

The ratio of strength between sporting and mortar powder, as indicated by these experiments, is 2.1; the reciprocal of that between the sizes of grain, as nearly as could be determined, being 2.66.

Safety Compound, Oriental Powder Company.—This mixture of potassium chlorate and gambier was selected as a type of the general class of explosives in which potassium chlorate is the oxydizing substance. As is well known, these mixtures are characterized by far quicker and more intense action than the nitrates; but they are also justly regarded as dangerous by reason of undue sensitiveness to friction.

This particular variety was introduced in this country by the Oriental Powder Company, and shortly after the war was considerably used in the oil wells of Pennsylvania and elsewhere. It has been driven from the market by the nitro-glycerine compounds, which have proved to be both stronger and safer to handle. This variety is inferior to some others of its general class, because very liable to cake, especially if exposed to warm weather. If kept on hand for any considerable length of time it greatly deteriorated from this caking, and also from moulding. The powder was supplied in three grades—X, XX, and XXX; but the boxes were often not marked, and the eye distinguished little difference between the grades. For these reasons, in framing the formula no distinction was attempted.

For work under water, the quickness of this powder renders it so much superior to any grade of gunpowder that it can hardly be considered commensurable with it. Thus, gunpowder enclosed in 2-inch pine disrupts the case into comparatively large pieces, often permanently compressed to one and a half inches; safety compound pulverizes it, so that only small slivers appear at the surface of the boiling water.

No charge of gunpowder acts quickly enough to upset the hardened-steel pins by which the energy developed by the explosion is transmitted to the leads in the gauges. The result is quite different with safety compound; and it has been found that only comparatively small charges could be measured in the rings from this cause. Indeed, two gauges placed inside an 18-pound charge were so jammed and upset that they could not be opened.

The effect upon the water over the torpedo is also different from that of a gunpowder explosion, being evidently more sudden and violent; fish are killed at a much greater distance; the three distinct sounds, already mentioned, are also a characteristic of this explosive.

The following table shows the results of the trials. The cases (as stated in Appendix A) were usually of pine, 1 inch thick, with a tamping of sawdust around the bag containing the powder.

Summary of safety-compound experiments.

No. of shot.	Charge.		Distance to gauge. (D)	Fuzes.			Mean pressure per square inch. (P)			Remarks.
	Weight. (C)	Submergence. (S)		No.	Priming.	Radius. (R)	Observed.	Comp.	Difference.	
	Pounds.	*Feet.*	*Feet.*			*Inches.*	*Pounds.*	*Pounds.*	*Pounds.*	
66	2	33	1.62	1	F. M	2.43	672	1,402	+ 730	Case, 2 inches wood.
235	5	35	1.62	2	S. C	2.62	4,661	4,470	− 191	Tin can.
43	6	32	1.12	2	F. M	2.78	6,589	7,349	+ 760	
53	6	32	1.12	2	do	2.78	9,580		−2,231	
44	12	32	1.12	2	do	3.50	17,741	16,676	−1,065	
54	13	32	1.12	2	do	3.57	24,255	17,970	−6,285	
48	18	32	1.12	2	do	4.01	23,114	26,925	+3,811	
64	18	33	1.62	2	do	4.01	10,980	......	......	Caked, mouldy.
141	18	35	1.62	2	do	4.01	9,582	......	......	Do.
142	18	35	1.62	1	do	5.05	8,570	......	.....	Do.
23	18	31	2.12	5	do	2.95	13,516	17,817	+4,301	Grade X.
16	18	31	2.12	5	S. C	2.95	18,117		− 300	Grade XXX.
20	18	31	2.12	5	F. M	2.95	12,257		+5,560	Grade X.
13	18	31	2.12	10	S. C	2.95	17,994	......	......	(*)
17	18	31	2.12	10	F. M	2.95	18,763	......	......	(†)
Mean							13,050	12,972	2,523	

* Grade XXX +18 pounds mortar powder

† Grade X +18 pounds mortar powder.

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The last two shots were fired to test the effect, in sub-aqueous explosions, of mixing safety compound half and half with gunpowder, a device said to be advantageous in rock blasting. The figures, compared with the three similar shots immediately preceding, seem to indicate that the gunpowder adds little or nothing to the forces developed under water.

The formula for safety compound, deduced from these observations by the process already explained, is the following, the ratio of strength as compared with mortar powder being 30.62 ± 1.53:

$$(14) \qquad P = \left(\frac{13383 \, S^{\frac{1}{40}} \quad C^{1.94}}{(D+1)^2 \quad \overline{R}} \right)^{\frac{2}{3}}$$

It is altogether probable that the greater quickness of the chlorate class may modify the value of the functions of C and R entering this formula, but the data not being sufficient to thoroughly discuss the point, no change has been considered advisable.

Discussion of the Formulæ.—Although it cannot be claimed that the foregoing formulæ are based on sufficient data to place them beyond the range of future improvement, it is certain that their general accordance with the observations is as good as that of the latter among themselves; and hence that they are entitled to be accepted as the best guide at present in generalizing upon the effect of varying certain of the conditions under which charges of explosive mixtures are used in torpedo warfare.

Thus, for example, the relative strength of the different explosives under trial is indicated with all needful precision *for use under water* by the two-third power of the constant K in these equations. As already seen, these relative values for the different grades of common gunpowder are so nearly inversely proportional to their sizes of grain that this rule may be adopted in making a practical estimate.

The small exponent of S in these formulæ shows, very conclusively, that the increased pressure of the water has but little effect upon the forces developed by the explosion. The numerical value of the function of the submergence in the intensity formula, only increases from $1\ 046^{\frac{2}{3}}$ to $1.111^{\frac{2}{3}}$ when this quantity changes from 6 feet to 68 feet, indicating a gain of only about 5 per cent.; and it will be noted that the measurements accord with this result.

The large value of the exponent of C throws much light upon the influence of the conflicting conditions affecting this quantity in gunpowder explosions. From the principle of the conservation of energy, if all the powder were consumed, this exponent must be nearly unity. The strength of the cases was far too little to produce this result, as is directly proved by shots 171 to 176, fired in the 3-foot ring. Five of them were fired in stout wooden boxes of 2-inch pine, each made to contain exactly 25 pounds of powder. The observed energies and pressures per square inch of surface exposed (mean of six gauges) were:

No. 171.	Mean energy, 1.48 foot-pounds;	mean pressure, 1,294 pounds.
No. 172.	Mean energy, 1.66 foot-pounds;	mean pressure, 1,346 pounds.
No. 173.	Mean energy, 1.42 foot-pounds;	mean pressure, 1,237 pounds.
No. 174.	Mean energy, 1.48 foot-pounds;	mean pressure, 1,283 pounds.
No. 176.	Mean energy, 1.43 foot-pounds;	mean pressure, 1,244 pounds.
Mean..............	1.49	1,281

The other shot was fired in a strong cast-iron torpedo about 1.5 inches thick, which also contained exactly 25 pounds, giving:

No. 175. Mean energy, 12.39 foot-pounds; mean pressure, 5,250 pounds.

These figures exhibit the enormous loss of power which results from employing barrels and similar cases to contain charges of gunpowder fired under water. An experiment of a quite different character, made in February, 1871, has a bearing upon this subject, and will therefore be reported here.

A charge of 50 pounds of mortar powder, in a 1-inch 50-pound box, was fired at Willets Point upon the surface of ice about 7 inches thick. Ten fuzes were used, well distributed through the powder. The explosion broke a circular hole through the ice 5 feet in diameter, surrounded by several concentric cracks extending about 1.5 feet further, with many radial cracks. The box was broken into small fragments, some of which were thrown to a great height. Unburned grains of powder were distributed quite uniformly over the ice, the most distant being about 70 feet. A radial belt 1 inch wide was laid off, and the number of grains on it were carefully counted; 875 being thus found in 851 running inches. One hundred grains troy of the powder were found by count to contain 1,618 grains. Hence, the area over which the powder was distributed being 2,275,000 square inches, with an average of about 1 grain of powder per square inch, it is easily computed that about 20 pounds of the 50-pound charge were thrown out unburned.

These facts prove that the foregoing formulæ are applicable only to explosions in *ordinary wooden torpedoes*, in which a large part of the potential energy of the explosive cannot be utilized; and they explain why great discrepancies are to be expected in results obtained from shots fired under similar conditions They also explain the reason why C has so large an exponent; namely, because within the limits and under the conditions of the experiments the larger the charge the more perfectly is it burned. This is but natural, since the interior grains surrounded by flame must be more perfectly consumed than if thrown at once into the water, as in a small charge.

The great importance of many well distributed points of ignition is shown by the function of R (the cube root), which enters the intensity formula. For example, let the mean pressure per square inch exerted upon a vessel 10 feet distant, by an explosion of 2,000 pounds of mortar powder placed 30 feet below the surface, be computed by equation (8).

With 1 fuze, $R = 24\ 3$; and $P = 23{,}730$ pounds.
With 2 fuzes, $R = 19.3$; and $P = 25{,}630$ pounds.
With 4 fuzes, $R = 15$; and $P = 27{,}870$ pounds.
With 8 fuzes, $R = 12$; and $P = 30{,}015$ pounds.
With 20 fuzes, $R = 9$; and $P = 33{,}040$ pounds.
With 66 fuzes, $R = 6$; and $P = 37{,}820$ pounds.
With 535 fuzes, $R = 3$; and $P = 47{,}650$ pounds.

These figures are based upon the supposition that a torpedo relatively as strong as those used in my trials is employed. The Confederates often used old steam boilers for such charges; and in that case even a higher scale of increase in intensity of action might probably be obtained.

The importance of a spherical form for the charge is a natural deduction from this analysis. The long cylinders adopted for obstruction removers during the late war (1 feet long by 12 inches in diameter) evidently must have involved an enormous waste of powder.

Large Detonating Primers.—As already stated, experiment developed no sensible difference in the explosive force of gunpowder fired under water which could be traced to the nature of the fuze priming. Twenty grains of fulminating mercury seemed often to be no more effective than a simple flame of gunpowder. It remained to extend the scope of the investigations still further in this direction.

An explosion is simply a chemical reaction, in or between molecules, by which a volume of heated gas much larger than that of the original substances is formed *suddenly*. Upon the degree of suddenness depends the possible intensity of the action. With mechanical mixtures the reaction can only occur after the lapse of a sensible, although, perhaps, very short, interval of time; thus, with gunpowder the grains must be first successively ignited and then consumed, involving a motion of the atoms through comparatively long distances. With chemical compounds, like nitro-glycerine, for example, the atoms, so to speak, are already in position; and the atomic change exacts comparatively very little atomic motion, and, consequently, so little time that we say the reaction is *instantaneous*, and call it detonation.

It is, nevertheless, true that by varying the circumstances under which explosion is produced very different intensities of action may be obtained from all or nearly all explosives Probably these variations form a series, giving several orders of explosion; but at present only two are generally recognized, viz, the first order (or detonation) and the second order.

This fact of variation in explosive force has long been recognized for chemical compounds, but recently* MM. Roux and Sarrau have extended it to musket powder, and claim that more than four times the usual explosive force may be obtained by using nitro-glycerine detonated by fulminating mercury as the primer. They, however, lay stress upon the condition that the detonating force must be exerted simultaneously upon all parts of the mass, which, of course, involves the use of primers relatively so large as to render the discovery of little practical value. In their reported experiments they employed 1.15 and 1.35 grammes of musket powder with, respectively, 0 2 and 0.3 grammes of fulminating mercury and 0.6 and 0.45 grammes of nitro-glycerine; *i. e.*, their detonators were considerably more powerful than their charges.

Thinking that, in explosions under water, where so much of the potential energy of the charge is usually lost, it might be possible to utilize a larger portion by employing a detonating primer of nitro-glycerine or gun-cotton, I made a few experiments to test the matter.

Six shots were fired in the 3-foot ring. Each charge was 48 pounds of musket powder, enclosed in and filling a tin can (No. 4). The submergence was 33 feet. For two shots, the primer, placed centrally in the charge, consisted of one-fourth of a pound of dynamite, in a paper cylinder 9 inches long, detonated by a service fuze containing 20 grains of fulminating mercury; for two of the others, the primers, similarly placed, consisted of a like amount of dry compressed gun-cotton inch discs, 9 inches long, detonated by an Abel fuze; the remaining shots were fired, for comparison, with a service fuze containing 20 grains of fulminating mercury. Two additional shots were fired, under similar conditions, to measure the work due to the dynamite primers. They were enclosed in small tin cylinders, just large enough to receive them, and were detonated by service fuzes, as before.

The following table exhibits the results of these experiments. Lest the forces developed by the simple primers be under-estimated, it may be well to remark that when they were fired alone, fish darted from the water at a distance of 100 yards, and that the shock in a boat vertically over the ring was so severe as to overturn a can.

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* Comptes Rendus, October 5, 1874.

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Experiments with large detonating primers.

No. of shot.	Gunpowder.	Primer.	Distance.	Mean of 6 gauges.	Pressure per square inch.
	Pounds.		*Feet.*	*Pounds.*	*Pounds.*
470	48	None	1. 12	5, 364	5, 481
471	48	None	1. 12	5, 598	
472	48	4-ounce dynamite	1. 12	7, 174	7, 475
473	48	4-ounce dynamite	1. 12	7, 776	
474	48	4-ounce gun-cotton....	1. 12	9, 528	9, 820
475	48	4-ounce gun-cotton ..	1. 12	10, 111	
476	None.	4 ounce dynamite	1. 12	5, 053	5, 105
477	None.	4-ounce dynamite	1. 12	5, 158	

These figures show that while the actual force developed was increased by the use of the primer, the gain did not equal that added by the primer itself. This result is confirmed by the appearance of a large piece of one of the cans, which was grooved by grains of gunpowder that had been driven against it like so much sand, under the sudden burst of gas from the primer.

Evidently, to derive the full theoretical advantage from this method of firing explosive mixtures, a case sufficiently large and strong to resist the explosion of the primer is requisite; but even with the weak cases usually employed for gunpowder the aggregate effect of charge and primer appears to largely exceed that due to the gunpowder alone; and, if these few trials can be trusted, gun-cotton appears to be superior to dynamite for this use.

Air-Chamber within the Torpedo.—The question has been mooted whether or not an air-chamber in the torpedo has an effect in determining the direction of the blast, and hence the line on which the maximum intensity of action is to be expected.

Experiments upon a small scale have been published proving that with cylindrical tin cases, 3 feet long and 6 inches in diameter, and an air space twice the length of the charge (10 pounds), no such directive influence is indicated.

These conditions are so different from those intended by the advocates of the theory, that the experiments have little bearing upon the practical question, which has been considered to be of sufficient importance to demand further experimental investigation. Accordingly, some special torpedo cases were prepared to receive 100-pound charges. They were strong oak kegs, of a capacity of 24 gallons, banded with six galvanized-iron hoops. Wooden diaphragms 1 inch thick were inserted across the middle, parallel to the heads, thus dividing the keg into equal compartments, one to be filled with gunpowder and the other with air.

These kegs, charged with various kinds of gunpowder, were slung centrally in the 4-foot ring, with the air end sometimes directed upward and sometimes downward. Their dimensions being 24 inches between heads, 18.5 inches in diameter in the middle, and 15.5 inches across the ends, all measured in the clear, it may easily be computed that the centre of the gunpowder charge was thus moved from its normal position (1.62 feet from the pin-heads of all the gauges) until it was 2.1 feet from the most distant, 1.7 feet from the horizontal, and 1.2 feet from the nearest gauges.

Now if we suppose the air-chamber to be removed—*i. e.*, the water to be admitted to the empty half of the torpedo—it is easy to compute the changes in P for each gauge, which should result from this displacement of the centre of the charge; and by comparing the observed lead indications with these computed results the actual effects of the air chamber may be determined. For example, the normal value of the function of D in the denominator of P, for shots fired centrally in the 4-foot ring, is:

$$(1.62+1)^{\frac{4}{3}}=3.61$$

After the change of position in the charge indicated above, it becomes:

For gauges next air chamber.. $(2.1+1)^{\frac{4}{3}}=4.52$

For middle gauges .... $(1.7+1)^{\frac{4}{3}}=3.76$

For gauges next powder chamber .... $(1.2+1)^{\frac{4}{3}}=2.86$

Mean 3.71

Hence, provided the air chamber has no directive effect upon the blast, the gauges next the air chamber should show $\frac{3.71}{4.52}=0.82$ of the mean; those in the middle $\frac{3.71}{3.76}=0.99$ of the mean; and those next the powder chamber $\frac{3.71}{2.86}=1.30$ of the mean. These ratios, of course, are based upon the law already deduced from a comparison of the different gauges, that the direction of the line of maximum intensity of action in gunpowder explosions is determined by the accidental circumstance of what part of the can is first ruptured, rather than by any normal upward tendency of the gas. To correct, however, for any possible tendency in the latter direction, the cases were placed sometimes with the air chamber up and sometimes down. The following figures exhibit the results of the experiments:

Effect of air chamber in torpedo.

No. of shot.	Powder.		Air end.	Mean P for all 6 gauges.	Gauges next air chamber.			Middle gauges.			Gauges next powder chamber.		
	Kind.	Weight.			Normal P	Obser'd P	Diff.	Normal P	Obser'd P	Diff.	Normal P	Obser'd P	Diff.
		Pounds.		*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
188	Mortar..............	100	Down...	4, 160	3, 411	4, 888	+ 1, 471	4, 118	3, 874	− 244	5, 406	3, 717	− 1, 689
187	....do	100	Up . ..	7, 848	6, 434	9, 440	+ 3, 006	7, 768	7, 850	+ 82	10, 200	6, 255	− 3, 945
223	Musket	100	Down...	5, 073	4, 160	6, 455	+ 2, 295	5, 022	4, 713	− 309	6, 595	4, 054	− 2, 541
190	....do..............	100	..do.....	7, 981	6, 545	13, 075	+ 6, 530	7, 902	6, 602	−1, 300	10, 377	4, 268	− 6, 109
387	....do............ ...	100	Up	4, 347	3, 565	3, 542	− 23	4, 303	4, 582	+ 279	5, 651	4, 916	− 735
189	....do..............	100	..do	6, 899	5, 658	7, 620	+ 1, 962	6, 830	6, 341	− 489	8, 968	6, 787	− 2, 181
368	Cannon	100	..do.....	1, 012	830	1, 107	+ 277	1, 003	977	− 26	1, 318	952	− 366
367	Mammoth..........	100	..do.....	324	266	337	+ 71	321	268	− 53	421	369	− 52
369	Oliver..............	72	..do	276	226	337	+ 111	273	225	− 48	359	268	− 91
	Algebraic sum........................			37, 920	31, 095	46, 801	+15, 706	37, 540	35, 432	−2, 108	49, 295	31, 586	−17, 709

These figures certainly indicate that a marked and practically a very useful effect was exerted by the air chamber upon the direction of the line of maximum intensity. Assuming the algebraic sum of the columns in the table to be the best determined index of this effect, we find that the middle gauges indicate nearly the pressures to be expected of them; that those next the air chamber show $\frac{46801}{31095} = 1.5$ more, and those next the powder chamber $\frac{49595}{31586} = 1.6$ less than would have been the case had there been no air chamber; and, lastly, that the relative gain from placing the air end rather than the powder end of the torpedo next a vessel would have been $\frac{46801}{31586} = 1.5$.

The reason of this gain is not difficult to understand. The gas first generated naturally rushes into the void, since that marks out the line of least resistance; and its inertia, developed by the resistance of the head to its further progress, brings a greater strain to bear at that point of the torpedo than on any other, and thus regulates the rupture, and consequently the direction of the burst of the gas into the water.

Both theory and experiment thus agree that an air chamber of suitable dimensions, in that end of a gunpowder torpedo which is placed next the vessel to be destroyed, is highly advantageous.

Effect of Recoil.—The reduction in the intensity of action due to a recoil in the vessel receiving the shock is a matter of the highest practical importance, and will soon be considered carefully under an independent heading. Here it is only proposed to give a brief statement of data bearing upon the subject, collected during the experiments with explosive mixtures.

It will be remembered that gauges were placed at the lower end of the buoy, and in shackles inserted at various points of the wire rope supporting the ring. Now, as the whole system floated freely in the water, a very slight force sufficed to raise the buoy 3 or 4 feet, and thus to allow all these gauges to recoil from the shock of the explosion. Even the smallest charges produced this result, while a large gunpowder torpedo often threw the whole apparatus into the air, even when the ring had been submerged 35 feet below the surface.

Again, in the earlier experiments a couple of gauges were often bedded in the powder itself, and recovered by means of a combined wire and hemp line attached to the socket outside the torpedo. The explosion, of course, shot these gauges out with high velocities, which must have absorbed energy that otherwise would have been registered on the leads.

The following table exhibits the consolidated data, all further details being given in Appendix A. The computations are made from the formulæ given above, D being zero for the torpedo gauge; 14 for the shackle gauge; and S — 7 for the buoy gauge. Averages are given for each charge of powder, in order to exhibit the effect of variations in the initial intensity:

Summary of movable gauge records.

No. of shots.	Charge.		Pressures—Buoy. D=S − 7			Pressures—Shackles. D=14			Pressures—Torpedo. D=0		
	Kind.	Weight.	Obs'd.	Comp.	Diff.	Ob	Comp.	Diff.	Obs'd.	Comp.	Diff.
		Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
6	Mortar	25	15	42	− 27	66	95	− 29	929	3, 508	− 2, 579
17	......do	50	50	119	− 69	88	224	− 136	3, 384	8, 564	− 5, 180
39	......do	100	90	238	− 148	183	571	− 388	6, 197	20, 833	− 14, 636
7	......do	150	147	449	− 302	257	975	− 718	9, 449	37, 071	− 27, 622
7	......do	200	201	371	− 170	193	1, 209	− 1, 016	7, 776	44, 744	− 36, 968
1	......do	300	612	443	+ 169	824	2, 149	− 1, 325	.....	......	......
6	Musket	48	76	338	− 312	....	......	......	.....	......	......
4	......do	100	156	300	− 144	108	727	− 619	.....	......	......
3	Cannon	100	28	36	− 8	21	88	− 67	62	3, 806	− 3, 744
3	Mammoth	100	9	17	− 8	12	41	− 29	156	1, 398	− 1, 242
2	Sporting	100	315	562	− 247	127	1, 352	− 1, 225	13, 044	50, 037	− 36, 993
1	Oliver	72	9	5	+ 4	11	27	− 17	.....	......	......
Grand mean			100	238	− 128	134	564	− 430	5, 641	20, 624	− 14, 983

The effect of recoil suggested by this table is so startling, and is based so much upon the indications of approximate formulæ, that a suspension of judgment is asked until the subject is again considered in connection with explosive compounds.

Summary of Results with Explosive Mixtures.—The general practical conclusions affecting the torpedo service, resulting from this discussion of the data for explosive mixtures, are the following:

I. The nitrate mixtures would be far inferior to the chlorates for use in torpedoes were it not for the dangers attending the handling of the latter. How much this should weigh in deciding between them will depend upon local circumstances.

II. If gunpowder be chosen as the explosive, the finest and the quickest grades are the most economical—indeed, none other should be employed.

III. Numerous well-distributed points of ignition are very desirable; and if large detonating primers are available, they should be used.

IV. Strength of case is of the highest importance. A small charge in a strong iron torpedo, when fired in the close vicinity of the enemy, is as effective as three or four times the amount in a wooden torpedo. Also, the nearer the form of case approaches a sphere the better.

V. An air chamber in the torpedo, equal to the charge in dimensions and cubic capacity, is decidedly advantageous, because it serves to direct the blast. This advantage is greater with stationary than with movable torpedoes, the increased bulk being an objection in the latter case.

VI. The relative strength of the different explosive mixtures for use under water appears from these experiments to be the following, mortar powder being adopted as the standard. For gunpowder, these ratios differ but little from the reciprocal of the ratio between the sizes of the grains, showing that the strength is nearly inversely proportional to the latter quantity:

Mammoth powder	0.08
Oliver powder	0.09
Cannon powder	0.18
Mortar powder	1.00
Musket powder	1.57
Sporting powder	2.61
Safety compound	30.62

VII To exhibit in a convenient form the approximate effect of variations in charge and distance, Plate IV has been prepared. The best sporting powder is adopted as the explosive. The submergence is uniformly assumed at 10 feet. One fuze is allowed for each 60 pounds of the powder (about a cubic foot); giving $n=\frac{C}{60}$ and $R=7.55$. These substitutions being made in equation (13), it can be placed under the following form:

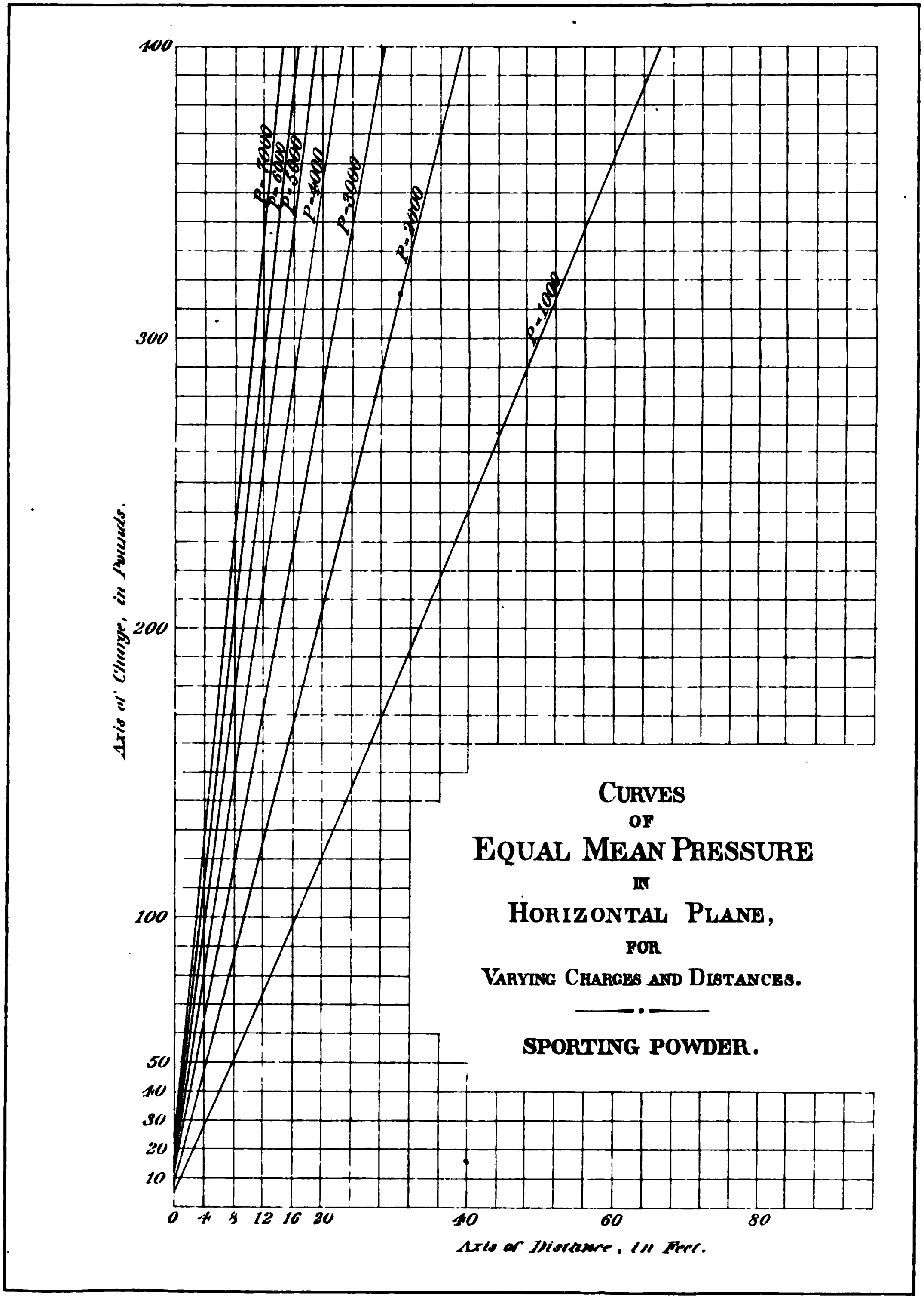
$$D=\frac{35.83\,C^{0.97}}{\sqrt[4]{P^3}}-1$$

The curves on the plate, computed by this formula, exhibit to the eye the relation between the charge and distance for various assumed values of P. The conditions which are to be fulfilled before such results can be secured in practice must be carefully borne in mind in studying these curves; they are exceptionally difficult.

VIII. Finally, in taking leave of explosive mixtures, emphasis should be laid upon the fact that although no labor has been spared either in collecting or discussing the data, the results obtained should be regarded rather as general than specific. The fundamental difficulty, which renders the investigation in a certain sense indeterminate, is that in a sub-aqueous explosion only a small portion of the potential energy represented by an explosive mixture can be transformed into the kinetic or practically available form; and what this portion is, cannot be certainly known in any experiment. This necessarily entails a large probable error in all numerical results. We shall now proceed to consider explosive compounds, with which no such difficulty will be encountered, and with which, as will soon be seen, a much higher degree of precision may be attained.

ANALYSIS OF THE DATA FOR EXPLOSIVE COMPOUNDS.

At the beginning of these investigations the impossibility of fully utilizing the theoretical potential energy of explosive mixtures when fired under water, and their constant liability to deterioration from accidental wetting, were both appreciated;



CURVES
OF
EQUAL MEAN PRESSURE
IN
HORIZONTAL PLANE,
FOR
VARYING CHARGES AND DISTANCES.

SPORTING POWDER.

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and it was, therefore, confidently expected that some variety of explosive compound would prove superior to any of them for use in submarine mining.

To make a judicious selection from this class of explosives, a systematic course of comparative measurements under water was undertaken. In such trials the condition of submergence is essential, and its converse is equally true, viz, that the conclusions reached as to the relative strength of the different varieties are applicable only to sub-aqueous explosions, and throw little light on their merits for ordinary mining or rock blasting; in other words, the relative value of different explosives for practical use depends as much upon the nature of the resistance to be overcome as upon their chemical composition.

Supplies of the Abel compressed gun-cotton, now adopted in the English torpedo service, and also of the new granulated form, were imported from Stowmarket; samples of various nitro-glycerine compounds in use in this country were obtained, and, to make the list complete, a small supply of picrate powder was added.

After extended trials it became evident that dynamite No. 1, consisting of 75 per cent. of nitro-glycerine absorbed by 25 per cent. of kieselguhr, was decidedly the best for our objects. Experiments with this explosive were then multiplied until the data needful to fully develop the laws which govern its action when exploded under water were secured. For this reason, and because it is a good type of the general class of explosive compounds, it will be considered first.

Dynamite (or Giant Powder) No. 1.—In planning these experiments the effect of motion in the body receiving the shock was only partially appreciated, but as they were extended it became evident that rigidity was essential to determinate results. In the present discussion, therefore, all data in which this condition was not absolutely secured will be left for future consideration.

In like manner it was soon discovered, that with explosive compounds the thinner and weaker the case the greater the energy registered upon the leads. Hence, shots fired in wooden boxes will be neglected for the present, those only being considered which were fired in tin, glass, rubber cloth, or other *thin* cases giving comparable results.

These omissions restrict the analysis to 143 shots fired in the rings, and 17 in the crate; *i. e.*, to about 1,500 gauge measurements.

The first step is to consider the general formula for the energy developed by a sub-aqueous explosion, already deduced, and to determine in what respects the quantities entering it are affected by the peculiar nature of this explosive, and by the mode in which the experiments were conducted. This formula (page 49) is the following:

$$(5) \qquad W = \frac{K\,(\vartheta + E)^t\,S^y\,C^x}{(D + A)^q\,R^z}$$

Care was taken, with both the ring and crate, to place the charge *symmetrically*

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with respect to the gauges; thus making the mean of their indications sensibly independent of variations in the direction of the line of action of the forces. Hence, $(\vartheta + E)^t$ in the general formula can be reserved for future consideration; *i. e.*, be temporarily assumed to be unity, provided the analysis be restricted to the mean of the gauges. This condition, of course, limits the applicability of the preliminary formula to the *horizontal plane containing the charge.*

In the experiments with explosive compounds, detonating fuzes only were employed, and care was taken, by priming them with 20 grains of fulminating mercury and by increasing their number in any doubtful shot, to ensure an explosion of the first order. This precaution eliminates R^z from the general energy formula, and reduces the exponent (x) of the charge to unity.

We have already seen with explosive mixtures—which being characterized by a more sustained although far inferior mean intensity, might be expected to be more affected by the absolute water pressure on the case than the compounds—that little gain results from increasing the submergence of the charge beyond a few feet. Indeed, the exponent of S in the pressure formula proved to be only $\frac{1}{60}$. Before introducing this quantity in the formula for explosive compounds, it seemed, therefore, well to examine the data. The following table exhibits them for the ring trials—covering 36 shots:

Analysis of submergence.

RING SHOTS.

No. of shots.	Explosive.		Distance to gauge. (D)	Depth.	Submergence. (S)	Per square inch.			Remarks.
	Kind.	Weight. (C)				Mean energy. (W)	Mean pressure. (P)	Difference from grand mean P.	
		Pounds.	*Feet.*	*Feet.*	*Feet.*	*Foot lbs.*	*Pounds.*	*Feet.*	
1	Dynamite No. 1	5	1. 62	120	20	91. 4	20, 241	+ 88	Grand mean. P = 20, 329
1	....do..............	5	1. 62	120	32	100. 4	21, 547	−1, 218	
3	....do..............	5	1. 62	87	35	102. 0	21, 740	−1, 411	
1	....do..............	5	1. 62	120	40	96. 5	20, 809	− 480	
1	....do..............	5	1. 62	120	50	80. 6	18, 419	+1, 910	
1	....do..............	5	1. 62	120	60	91. 6	20, 100	+ 229	
1	....do..............	5	1. 62	120	70	89. 3	19, 847	+ 482	
1	....do..............	5	1. 62	115	80	102. 8	21, 772	−1, 443	
1	....do..............	5	1. 62	115	100	83. 3	18, 483	+1, 846	
18	Dualin	3	1. 62	16	6	72. 3	17, 293	− 328	Grand mean. P = 16, 965
3	....do..............	3	1. 62	94	35	68. 2	16, 636	+ 329	
1	....do..............	5	2. 12	108	35	46. 7	12, 930	− 259	Grand mean. P = 12, 671
1	....do..............	5	2. 12	108	68	44. 2	12, 412	+ 259	
1	Gun-cotton..........	4	2. 12	80	35	21. 5	7, 666	+ 49	Grand mean. P = 7, 715
1	....do..............	4	2. 12	108	68	22. 0	7, 765	− 50	

The figures of this table establish the fact that variations in the submergence, between the limits of 6 and 100 feet, produce no sensible effect upon the energy or mean pressure developed by the explosion. To carry the investigation still further, two shots were fired, one in the 4-foot ring and the other in the crate. Each will be considered in turn.

The 4-foot ring (shot No. 260) was suspended from a crane over the water, so that the top of the case (No. 1) containing a charge of 3 pounds of dualin was just awash. This left gauges Nos. 1 and 2 in the air; Nos 3 and 4, about 0.4 feet under water; and Nos. 5 and 6, 2 feet under water. The explosion made a tremendous report, and threw a jet of water about 150 feet into the air; many fish were killed; fragments of the tin can made indentations in the iron of the upper sockets and gauges.

Shots Nos. 124, 231, and 234 were identical with No. 260, except in being submerged 35 feet. The following table exhibits the mean pressures indicated by the leads exposed to these four explosions:

Three pounds of dualin in the four-foot ring.

No. of gauge.	Mean pressure per square inch.			
	Shot 260. (Charge awash.)	Shot 124. (Submergence, 35 feet.)	Shot 231. (Submergence, 35 feet.)	Shot 234. (Submergence, 35 feet.)
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
1	9, 902 (in air.)	20, 366	16, 018	16, 664
2	3, 445 (in air.)	17, 576	21, 210	17, 398
3	5, 725	15, 928	18, 625	17, 035
4	6, 615	16, 383	16, 290	16, 109
5	17, 950	15, 479	14, 862	13, 303
6	11, 453	14, 671	16, 570	14, 957

Comparing the means of corresponding submerged gauges in this table, we have the following result:

	Pounds.
Gauges 3 and 4, 0.4 foot below surface; charge awash	6, 170
Gauges 3 and 4; charge submerged 35 feet	16, 728
Difference	10, 558
Gauges 5 and 6, 2 feet below surface; charge awash	14, 701
Gauges 5 and 6; charge submerged 35 feet	14, 973
Difference	272

Although the top of the case was only air-tamped, these figures indicate that this condition caused no sensible reduction of pressure at a depth of 2 feet below the surface; but at 0.4 foot below that plane a marked loss occurred. The shot, therefore, strongly confirms the inference that S is affected with so small a fractional exponent as to become practically unity in the formula.

The crate shot (No. 293) was fired from a wharf, the instrument being suspended in such a manner as to bring the top of the iron work just awash. The charge was 5 pounds of No. 1 dynamite, in case No. 2; the submergence was 6 feet; the jet was about 25 feet high. Six other shots were fired under nearly identical conditions,

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except in respect to the submergence, and the following table exhibits a comparison of the results:

Analysis of submergence.

CRATE SHOTS.

No. of shot.	Weight of charge. (C)	Depth.	Submergence. (S)	Mean pressures per square inch.			Remarks.
				Top of crate. 18 gauges.	Bottom of crate. 18 gauges.	Mean of crate. 36 gauges.	
	Pounds.	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
195	5	112	42	815	887	851	Crate level.
225	5	80	29	884	816	850	Do.
217	5	100	36	906	807	857	Inclined 25° to horizon.
218	5	87	36	985	979	982	Do.
346	5	88	39	928	938	933	Inclined 53° to horizon.
347	5	88	39	943	878	911	Do.
293	5	16	6	1,163	1,005	1,084	Crate level—top awash.
Mean (excluding No. 293)......				910	884	897	

There were some extraordinary features connected with shot No. 293, which will be considered hereafter; but it is evident from this table that its comparatively slight submergence was ample to develop all the energy and intensity of action due to the charge; and hence that it accords with the foregoing data in indicating that no function of the submergence need be introduced into the general formula.

In fine, then, the general formula (equation 5), when representing the energy developed by explosive compounds in the horizontal plane containing the charge, may be simplified as follows:

$$(15) \qquad W = \frac{K\ C}{(D + A)^q}$$

In this expression K is a constant depending upon the explosive employed; the exponent q must be nearly 2, in fact would be exactly two except for the loss of energy arising from the water being slightly compressible; and the constant A is dependent for its value upon the energy developed at the centre of the charge.

If it were possible to determine A by direct measurement the advantage would be great; but, as I was convinced by a few preliminary experiments, the forces developed are so tremendous, even with miniature charges, that it is quite impracticable to do so. Although these attempts resulted in nothing definite, they will be put on record here as at least confirmatory of the ultimate conclusions derived from the analysis.

The experiments were conducted by placing upright, upon a solid foundation, a No. 2 pressure gauge, of which the piston had been lengthened so as to extend outside the cap, and terminate in a strong steel disc 3 inches in diameter and 0.75 inches thick, making the whole movable part weigh 2.5 pounds. The piston was supported on a $\frac{75}{100}$ lead in the usual manner, and the sample of the explosive to be tested was laid on the disc. No tamping of any kind was employed. The whole force of the explosion (in the air) was thus to be transmitted directly to the lead cylinder by a steel cylinder 0.35 inches in diameter.

The charges uniformly weighed 508 Troy grains, and were put in paper cylinders, all 1.25 inches in diameter except for shot No. 9, which was 0.9 inches. Shot No. 1 was laid on its side, the rest being placed on end.

The following table exhibits the energies and pressures registered by the leads in these trials; which, however, were only small fractions of the total quantities developed. The first shot (dynamite) snapped off the steel piston at its junction with the disc, probably because not placed quite centrally upon it. A piece of file laid between the charge and disc was pulverized, and its cuttings were stamped upon the disc. A piece of half-inch wrought iron similarly placed under a cartridge of gun-cotton was stamped with the exact shape of the latter on its top, and with the centre point made by the lathe on its bottom. The piston was upset; the disc was cracked; and, in fine, all the explosives, except safety compound, left such marks of intense action on the apparatus that it was evidently impossible to measure the whole forces developed. The safety compound exhibited the combustion characteristic of all mixtures, small particles being thrown burning into the air.

Experiments in air.

[Charge 508 grains Troy, untamped.]

No. of shot.	Charge.	Lead shortening.	Registered energy. Net.	Registered pressure. Net.	Remarks.
		Inches.	*Foot-pounds.*	*Pounds.*	
1	Dynamite No. 1	0.515	173.7	14,437	Cartridge on side. Broke piston.
2	......do	0.438	129.9	11,900	Stamped shape on iron support.
3	......do	0.185	33.5	4,820	Do.
4	Safety compound	0.004	0.25	185	Burning grains thrown off.
5	......do	0.006	0.4	252	Do.
6	Gun-cotton	0.356	90.0	9,318	Upset piston. Cracked disc.
7	......do	0.258	54.3	6,651	Stamped its shape on iron support.
8	Dualin, frozen	0.263	55.9	6,778	Stamped lathe mark on iron support.
9	......do	0.270	58.1	6,958	Do.
10	Dualin, soft	0.247	50.8	6,360	Indented iron support.
11	......do	0.211	40.3	5,450	Do.

Having thus failed to devise any method by which the quantity A in equation (15) could be directly measured, it only remained to determine the numerical values of the three constants by analysis.

The problem was one in which little assistance could be derived from the method of least squares; for the compressions of the more distant leads were registered at an unfavorable part of the scale, and the precise relative weight to be assigned them as compared with those nearer the charge could hardly be fixed. Moreover, the well known physical conditions that A must be exceedingly small, and that q must be

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slightly larger than two, rendered a study by the graphical method comparatively easy, and it was accordingly adopted.

As already stated the data were ample, covering variations in the charge (C) between the limits of 0.25 pounds and 200 pounds, and in the distance (D) between 1.12 and 80 feet. All essential details will be found in the next table, or in Appendix A or B.

The following equation, applicable only to the horizontal plane containing the charge, resulted from studying these data, the final modifications being adopted in June, 1878.

$$W = \frac{58\ C}{(D + 0.01)^{2.1}} \tag{16}$$

To pass from this energy formula to the corresponding expression for the mean pressure per square inch developed by the explosion, combine equations (6) and (16), giving:

$$P = \sqrt[3]{\left(\frac{1832000\ C}{(D+0.01)^{2.1}}\right)^2} \tag{17}$$

Comparing these two expressions it appears that while the available energy of the explosive is directly proportional to the charge and inversely proportional to the square of the distance (nearly), the intensity of action (mean pressure) varies directly with the two-thirds power of the charge and inversely with the 1.4 power of the distance.

The reason for the very limited range of the destructive effects of large sub-aqueous explosions is apparent from these formulæ.

The following table exhibits, in a compact form, the data obtained from the ring trials and employed in this investigation, together with the degree of accordance between the measurements and the indications of the formula deduced therefrom. The last shot (No. 524) was fired after the latter was finally adopted; and the close accordance between theory and an observation which so greatly exceeded the limits of the data available in the investigation, is a very satisfactory confirmation of the precision of the analysis:

Summary of experiments with dynamite No. 1.

RING SHOTS.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) (Mean of six gauges.)			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
476	0.25	33	3	1.12	5,053	4,636	+ 417	
477	0.25	33	3	1.12	5,158		+ 522	
263	0.50	6	4	1.62	4,565	4,760	− 195	
264	0.50	6	4	1.62	5,048		+ 288	
265	0.50	6	4	1.62	5,338		+ 578	
266	0.50	6	4	1.62	5,515		+ 755	
267	0.50	6	4	1.62	5,040		+ 280	
268	0.50	6	4	1.62	4,996		+ 236	
269	0.50	6	4	1.62	5,234		+ 474	
270	0.50	6	4	1.62	4,682		− 78	
271	0.50	6	4	1.62	4,697		− 63	
272	0.50	6	4	1.62	4,655		− 105	
273	0.50	6	4	1.62	4,817		+ 57	
274	0.50	6	4	1.62	4,857		+ 97	
275	0.50	6	4	1.62	5,825		+ 1,065	
276	0.50	6	4	1.62	5,255		+ 495	
277	0.50	6	4	1.62	4,778		+ 18	
278	0.50	6	4	1.62	4,513		− 247	
279	0.50	6	4	1.62	4,884		+ 124	
280	0.50	6	4	1.62	4,199		− 561	
281	0.50	6	4	1.62	4,409		− 351	
282	0.50	6	4	1.62	3,744		− 1,016	
283	0.50	6	4	1.62	4,441		− 319	
284	0.50	6	4	1.62	3,893		− 867	
285	0.50	6	4	1.62	5,243		+ 483	
286	0.5	6	4	1.62	4,493		− 267	
287	0.5	6	4	1.62	3,918		− 842	
288	0.5	6	4	1.62	4,176		− 584	
289	0.5	6	4	1.62	4,524		− 236	
290	0.5	6	4	1.62	4,110		− 650	
291	0.5	6	4	1.62	4,572		− 188	
292	0.5	6	4	1.62	4,023		− 737	
78	1.0	32	3	1.12	12,204	12,620	− 416	
483	1.0	33	3	1.12	13,029		+ 409	
484	1.0	33	3	1.12	12,375		− 245	
96	1.0	35	4	1.62	9,193	7,555	+ 1,638	
183	1.0	35	4	1.62	8,903		+ 1,348	
184	1.0	35	4	1.62	9,299		+ 1,744	
209	1.0	35	4	1.62	7,168		− 387	Dynamite made at Willets Point.
357	1.0	35	4	1.62	8,417		+ 862	
452	1.0	35	4	1.62	8,205		+ 650	
453	1.0	35	4	1.62	8,402		+ 847	
454	1.0	35	4	1.62	8,535		+ 980	
455	1.0	35	4	1.62	8,206		+ 651	
456	1.0	35	4	1.62	8,838		+ 1,283	
457	1.0	35	4	1.62	8,048		+ 493	
458	1.0	35	4	1.62	8,162		+ 607	
459	1.0	35	4	1.62	7,746		+ 191	
460	1.0	35	4	1.62	8,112		+ 557	

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Summary of experiments with dynamite No. 1—Continued.

RING SHOTS—Continued.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) (Mean of six gauges.)			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
143	1.0	35	5	2.12	5,082	5,194	− 162	
501	1.0	23	5	2.12	4,951		− 243	
502	1.0	23	5	2.12	4,936		− 258	
503	1.0	23	5	2.12	4,820		− 374	
504	1.0	23	5	2.12	4,628		− 566	
79	2.0	32	3	1.12	19,552	20,030	− 478	
485	2.0	33	3	1.12	20,075		+ 45	
486	2.0	33	3	1.12	19,557		− 473	
97	2.0	35	4	1.62	14,390	11,880	+ 2,510	
211	2.0	35	4	1.62	14,265		+ 2,385	Dynamite made at Willets Point.
358	2.0	35	4	1.62	13,861		+ 1,981	
146	2.0	35	5	2.12	8,823	8,245	+ 568	
505	2.0	33	5	2.12	8,973		+ 728	
506	2.0	33	5	2.12	8,413		+ 168	
507	2.0	33	5	2.12	10,104		+ 1,859	
508	2.0	33	5	2.12	7,856		− 389	
80	3.0	32	3	1.12	27,801	26,240	+ 1,561	
487	3.0	33	3	1.12	25,696		− 544	
488	3.0	33	3	1.12	25,106		− 1,134	
359	3.0	35	4	1.62	15,441	15,710	− 269	
98	3.0	35	4	1.62	16,121		+ 411	
196	3.0	35	4	1.62	17,005		+ 1,295	
197	3.0	35	4	1.62	16,037		+ 317	
198	3.0	35	4	1.62	16,765		+ 1,055	
199	3.0	35	4	1.62	16,429		+ 719	
200	3.0	35	4	1.62	15,786		+ 76	
201	3.0	35	4	1.62	13,893		− 1,817	
202	3.0	35	4	1.62	17,650		+ 1,940	
203	3.0	35	4	1.62	16,961		+ 1,251	
213	3.0	35	4	1.62	17,366		+ 1,656	Dynamite made at Willets Point.
405	3.0	35	4	1.62	17,413		+ 1,703	Dynamite on hand five years.
406	3.0	35	4	1.62	16,015		+ 305	Dynamite on hand five years.
407	3.0	35	4	1.62	17,458		+ 1,748	Dynamite on hand three years.
408	3.0	35	4	1.62	16,116		+ 406	Do.
409	3.0	35	4	1.62	16,546		+ 836	Dynamite just made.
410	3.0	35	4	1.62	15,398		− 312	Do.
420	3.0	35	4	1.62	18,100		+ 2,390	Charge in rubber bag.
421	3.0	35	4	1.62	16,991		+ 1,281	Do.
422	3.0	35	4	1.62	14,623		− 1,087	
423	3.0	35	4	1.62	14,602		− 1,108	
424	3.0	35	4	1.62	13,850		− 1,860	
425	3.0	35	4	1.62	15,482		− 228	
426	3.0	35	4	1.62	17,209		+ 1,499	
427	3.0	35	4	1.52	15,873		+ 163	
449	3.0	35	4	1.62	16,192		+ 482	
450	3.0	35	4	1.62	15,317		− 393	
451	3.0	35	4	1.62	15,367		− 343	
464	3.0	35	4	1.62	14,577		− 1,133	
467	3.0	35	4	1.62	16,219		+ 509	

Summary of experiments with dynamite No. 1—Continued.

RING SHOTS—Continued.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) (Mean of six gauges)			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
147	3.0	35	5	2.12	10,529	10,800	− 271	
509	3.0	33	5	2.12	11,146		+ 346	
510	3.0	33	5	2.12	11,313		+ 513	
511	3.0	33	5	2.12	10,348		− 452	
512	3.0	33	5	2.12	11,155		+ 355	
90	4.0	35	4	1.62	20,727	19,040	+ 1,687	
214	4.0	35	4	1.62	18,487		− 553	Dynamite made at Willets Point.
360	4.0	35	4	1.62	17,171		− 1,879	
152	4.0	35	5	2.12	12,038	13,090	− 1,052	
513	4.0	33	5	2.12	13,240		+ 150	
514	4.0	33	5	2.12	13,764		+ 674	
515	4.0	33	5	2.12	13,732		+ 642	
516	4.0	33	5	2.12	13,113		+ 23	
361	5.0	35	4	1.62	19,398	22,100	− 2,702	
186	5.0	35	4	1.62	22,469		+ 369	
216	5.0	35	4	1.62	23,168		+ 1,068	Dynamite made at Willets Point.
224	5.0	35	4	1.62	22,655		+ 555	
294	5.0	100	4	1.62	18,483		− 3,617	
295	5.0	80	4	1.62	21,772		− 328	
296	5.0	70	4	1.62	19,847		− 2,253	
297	5.0	60	4	1.62	20,100		− 2,000	
298	5.0	50	4	1.62	18,419		− 3,681	
299	5.0	40	4	1.62	20,809		− 1,291	
300	5.0	32	4	1.62	21,547		− 553	
301	5.0	20	4	1.62	20,241		− 1,859	
517	5.0	33	5	2.12	13,358	15,200	− 1,842	
518	5.0	33	5	2.12	13,560		− 1,640	
519	5.0	33	5	2.12	12,974		− 2,226	
520	5.0	33	5	2.12	12,120		− 3,080	
521	5.0	33	5	2.12	12,745		− 2,455	
489	8.0	46	8	3.62	8,872	9,829	− 957	
490	8.0	44	8	3.62	9,370		− 459	
491	8.0	44	8	3.62	8,382		− 1,447	Ring slightly bent.
492	8.0	44	8	3.62	7,923		− 1,906	Ring bent.
493	8.0	44	8	3.62	8,224		− 1,605	Do.
496	10.0	44	8	3.62	8,839	11,432	− 2,593	Ring badly bent.
497	10.0	44	8	3.62	8,328		− 3,104	Do.
498	10.0	44	8	3.62	8,560		− 2,872	Do.
499	10.0	44	8	3.62	8,078		− 3,354	Do.
500	10.0	44	8	3.62	8,140		− 3,292	Do.
522	10.0	35	8	3.62	9,425		− 2,007	
523	10.0	35	8	3.62	8,801		− 2,631	
331	100	12	3	70.00	1,141	842	+ 299	Buoyant torpedo.
332	200	21	3	80.00	1,365	1,109	+ 256	Ground torpedo.
524	500	13	4	130.00	1,000	1,040	− 40	Do.
Arithmetical means					11,427	11,598	968	

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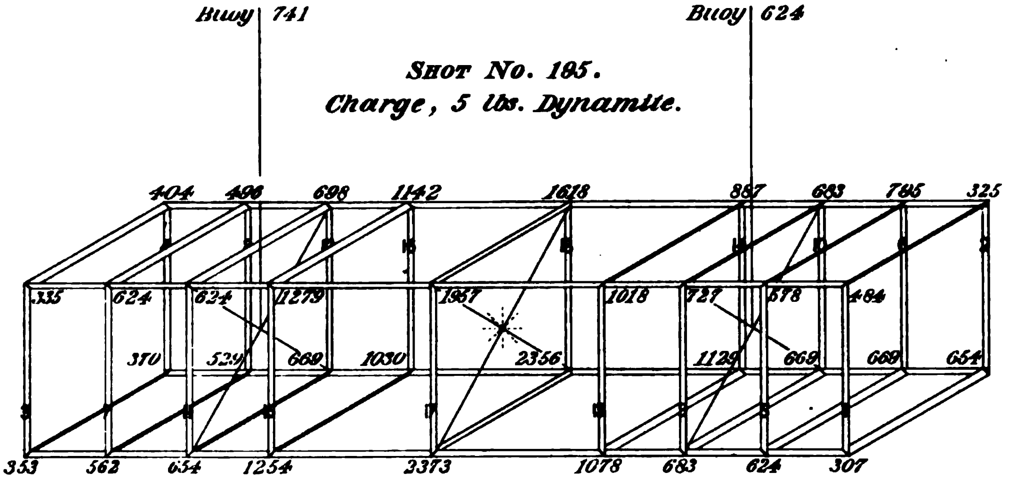
The following table gives for the crate shots, the same information which the last table supplies respecting the ring measurements. These data are specially valuable, because they extend the study laterally to considerable distances from the charge, and for this reason they are exhibited to the eye on Plates V to XI.

Summary of experiments with dynamite No. 1.

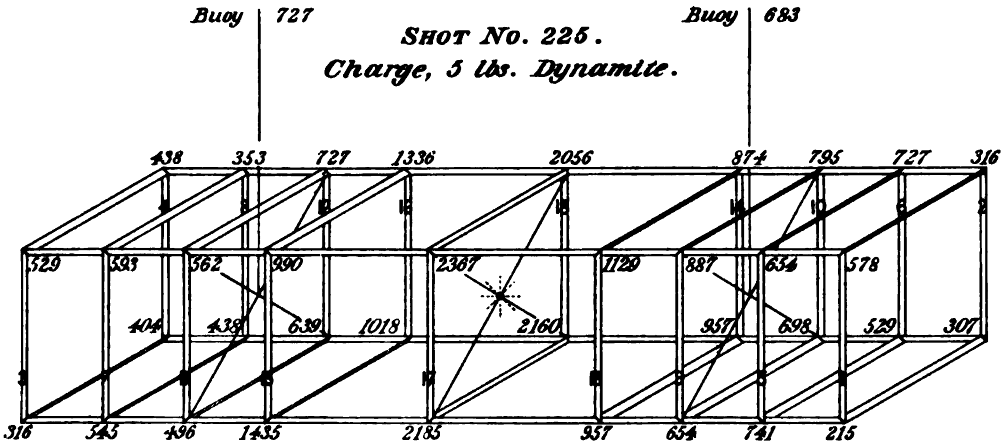
CRATE SHOTS.

No. of shot.	Inclination of crate axis to horizon.	Charge.		Distance to gauges. (D)	Pressure per square inch. (P) (Mean of six gauges.)			Remarks.
		Weight. (C)	Submergence. (S)		Observed.	Computed.	Difference.	
	°	*Pounds.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
195	0	5	42	6.5	2,076	3,178	— 1,102	
217	25	5	36	6.5	2,304		— 874	
218	25	5	36	6.5	2,437		— 741	
225	0	5	29	6.5	2,192		— 986	
346	53	5	39	6.5	2,554		— 624	
347	53	5	39	6.5	2,229		— 949	
195	0	5	42	11.8	1,102	1,381	— 279	
217	25	5	36	11.8	1,034		— 347	
218	25	5	36	11.8	1,101		— 280	
225	0	5	29	11.8	1,087		— 294	
346	53	5	39	11.8	1,155		— 226	
347	53	5	39	11.8	1,093		— 288	
195	0	5	42	16.1	676	864	— 188	
217	25	5	36	16.1	717		— 147	
218	25	5	36	16.1	979		+ 115	
225	0	5	29	16.1	683		— 181	
346	53	5	39	16.1	678		— 186	
347	53	5	39	16.1	863		— 1	
195	0	5	42	20.7	610	629	— 19	
217	25	5	36	20.7	550		— 79	
218	25	5	36	20.7	603		— 26	
225	0	5	29	20.7	573		— 56	
346	53	5	39	20.7	545		— 84	
347	53	5	39	20.7	655		+ 26	
195	0	5	42	25.5	404	470	— 66	
217	25	5	36	25.5	402		— 68	
218	25	5	36	25.5	515		+ 45	
225	0	5	29	25.5	388		— 82	
346	53	5	39	25.5	501		+ 31	
347	53	5	39	25.5	506		+ 36	
226	0	10	42	6.5	4,207	5,046	— 839	
343	0	10	42	6.5	4,535		— 511	
344	25	10	36	6.5	4,796		— 250	
345	25	10	36	6.5	4,695		— 351	
226	0	10	42	11.8	1,987	2,192	— 205	
343	0	10	42	11.8	1,800		— 392	
344	25	10	36	11.8	2,136		— 56	
345	25	10	36	11.8	2,139		— 53	
226	0	10	42	16.1	1,394	1,371	+ 23	
343	0	10	42	16.1	1,204		— 167	
344	25	10	36	16.1	1,369		— 2	
345	25	10	36	16.1	1,334		— 37	

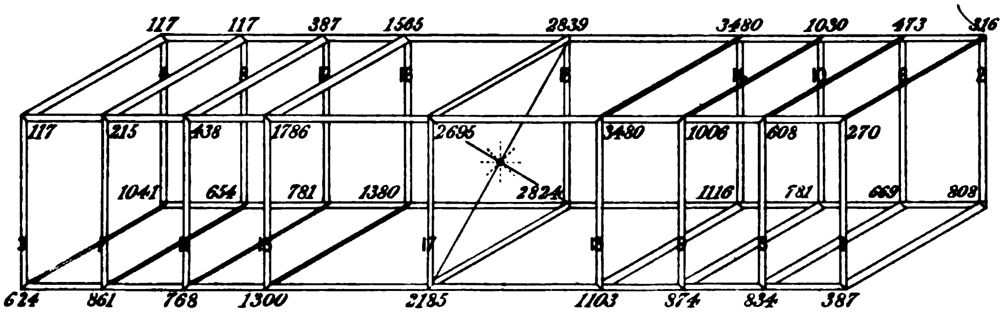
SHOT No. 195.
Charge, 5 lbs. Dynamite.



SHOT No. 225.
Charge, 5 lbs. Dynamite.



SHOT No. 293.
Charge, 5 lbs. Dynamite.
(Dock Shot.)



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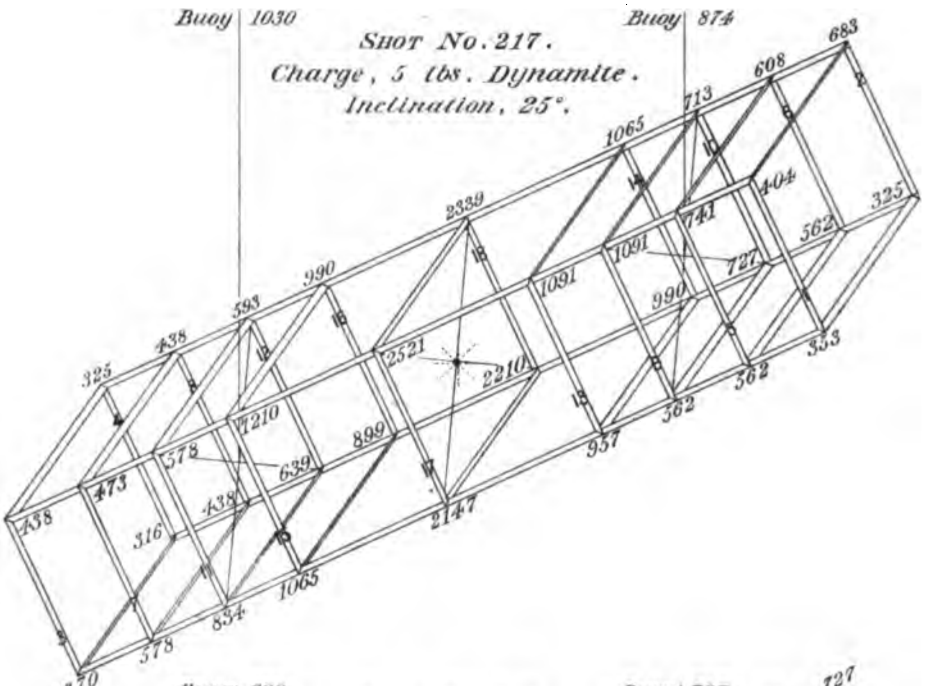
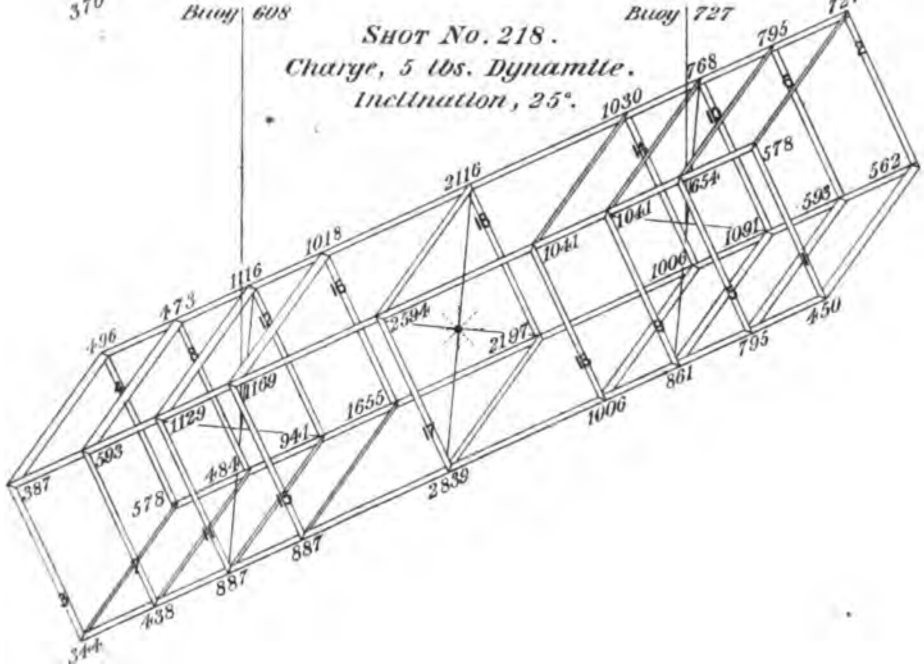
SHOT No. 217.
Charge, 5 lbs. Dynamite.
Inclination, 25°.



SHOT No. 218.
Charge, 5 lbs. Dynamite.
Inclination, 25°.



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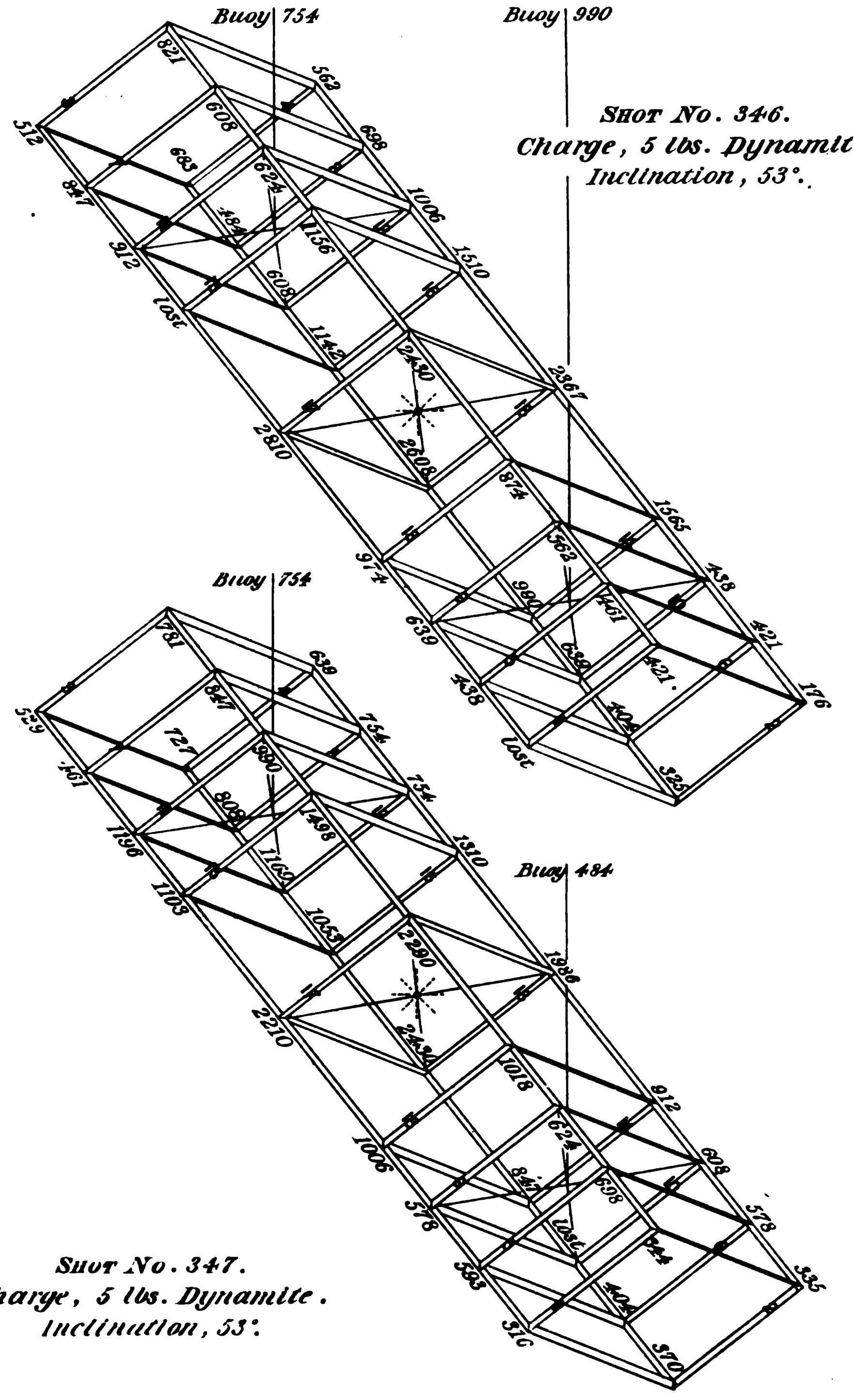

Shot No. 346.
Charge, 5 lbs. Dynamite.
Inclination, 53°.

Shot No. 347.
Charge, 5 lbs. Dynamite.
Inclination, 53°.

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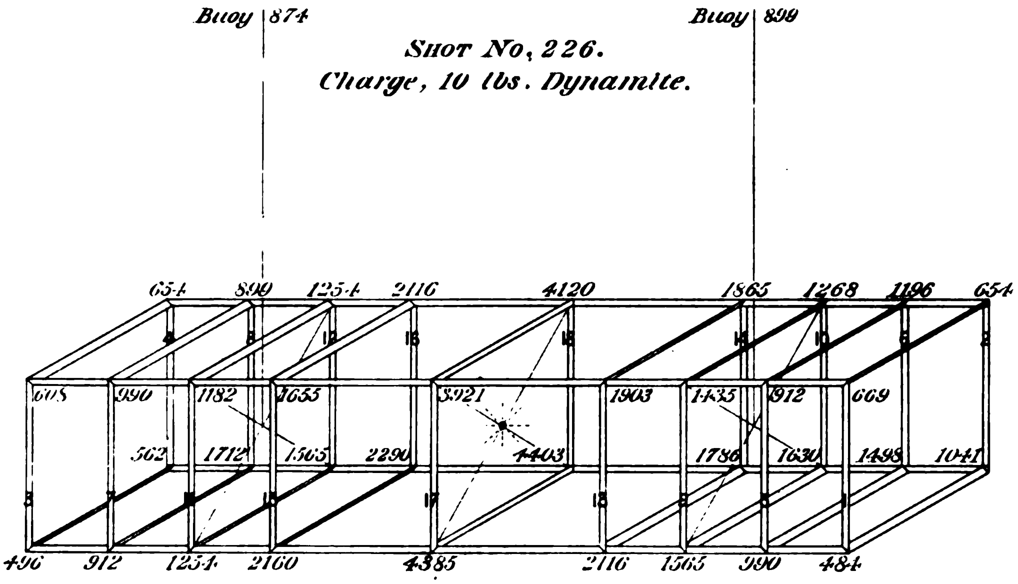
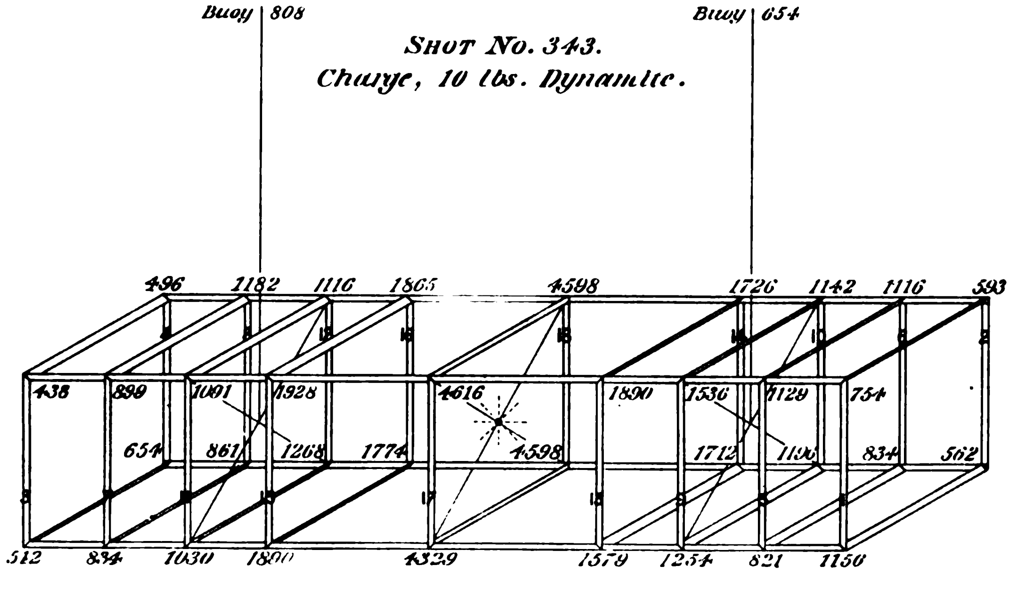
Shot No. 226.
Charge, 10 lbs. Dynamite.



Shot No. 343.
Charge, 10 lbs. Dynamite.



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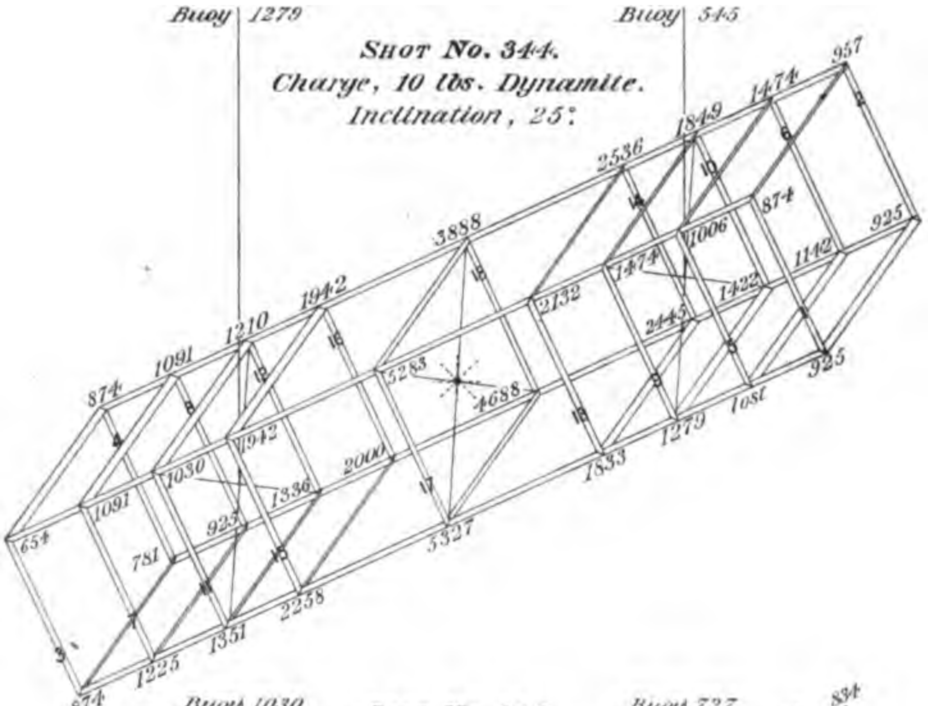
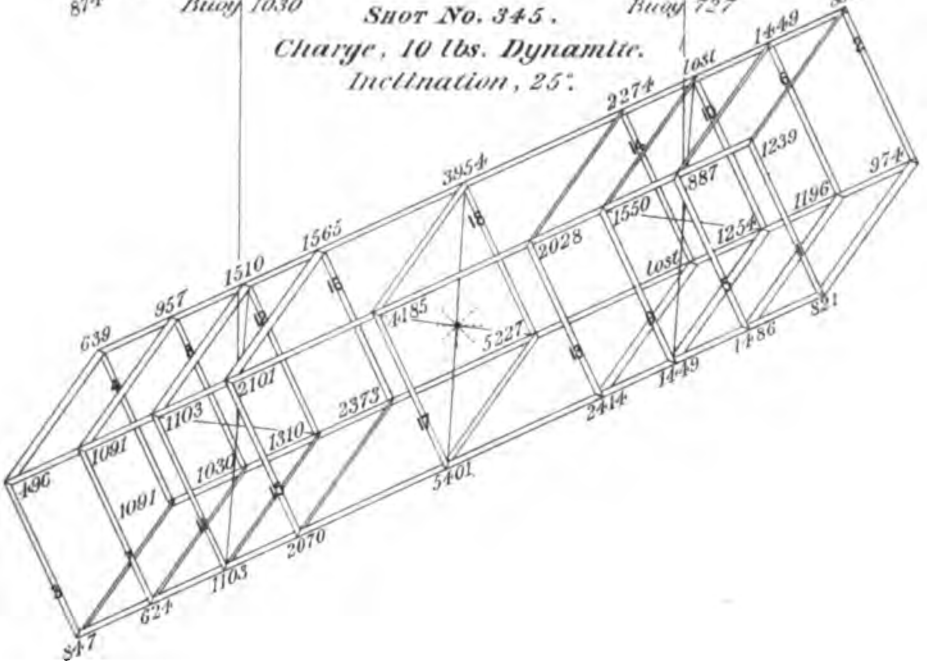


SHOT No. 344.
Charge, 10 lbs. Dynamite.
Inclination, 25°.



SHOT No. 345.
Charge, 10 lbs. Dynamite.
Inclination, 25°.

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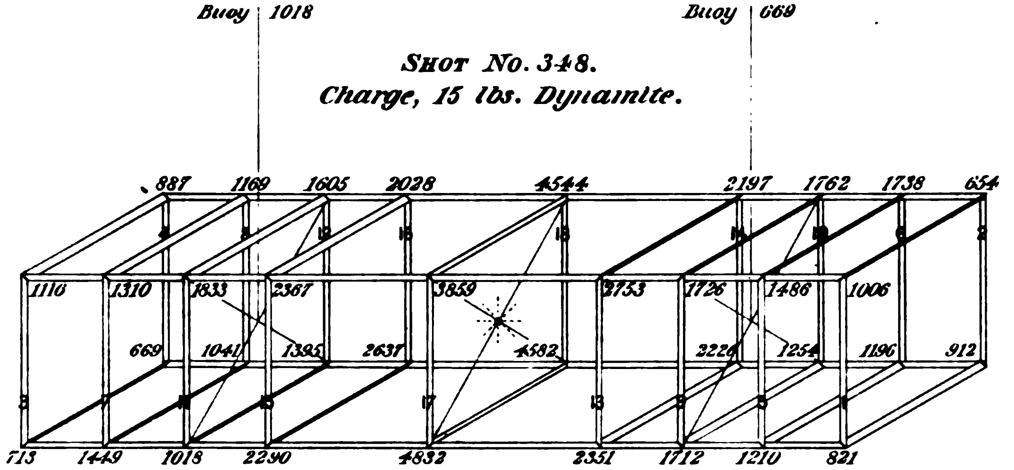
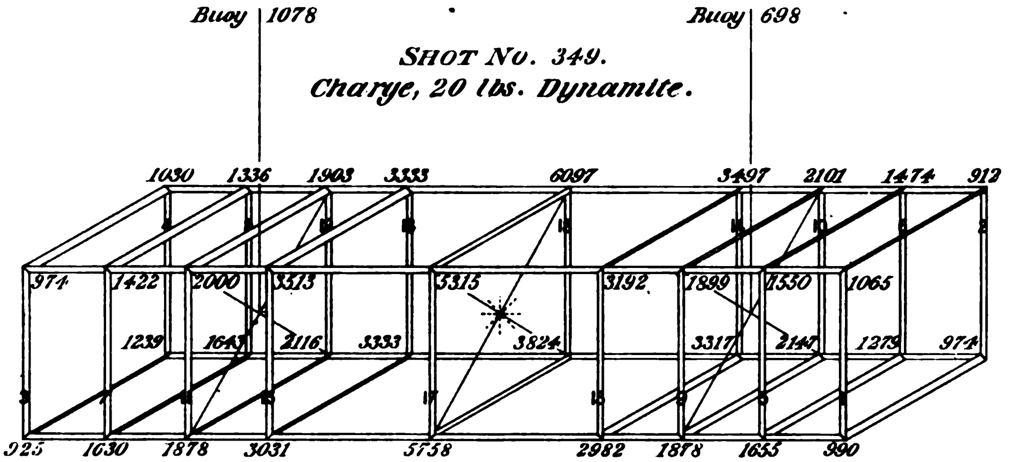
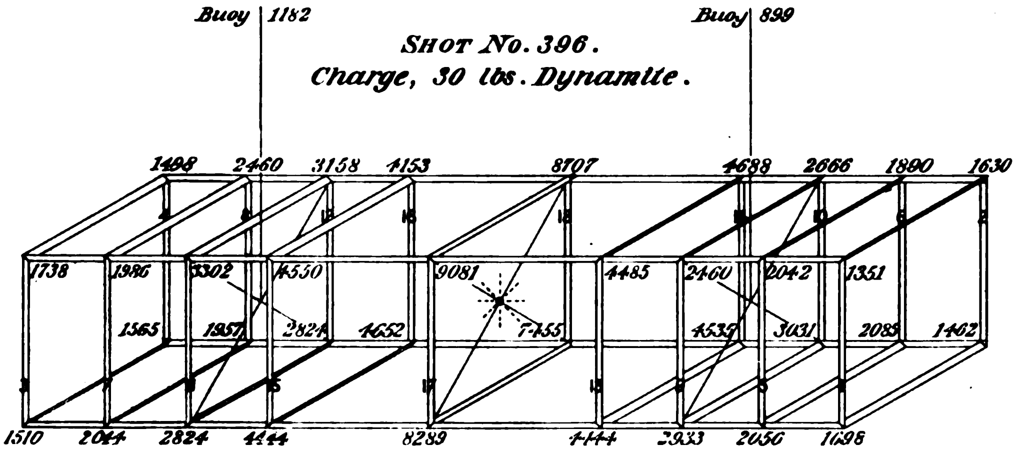
SHOT NO. 348.
Charge, 15 lbs. Dynamite.



SHOT NO. 349.
Charge, 20 lbs. Dynamite.



SHOT NO. 396.
Charge, 30 lbs. Dynamite.



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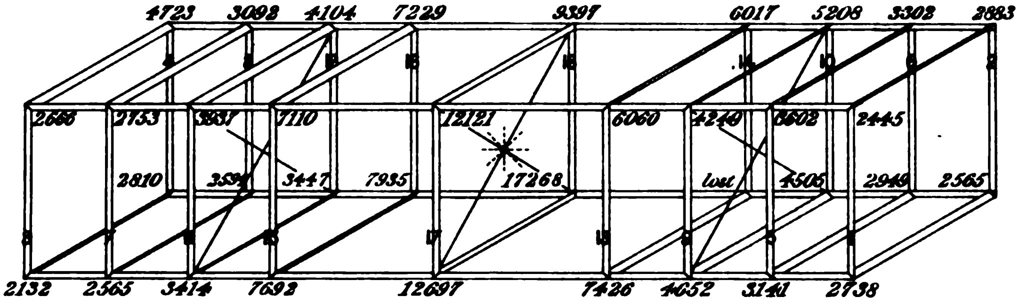
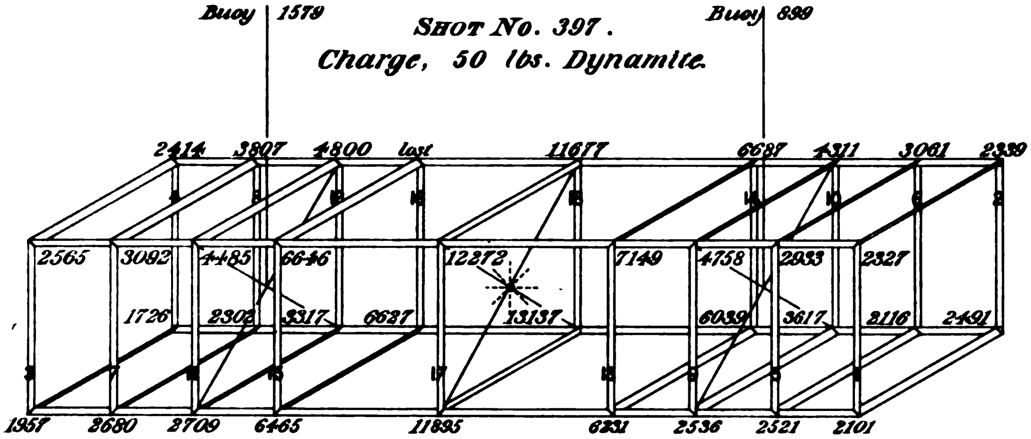
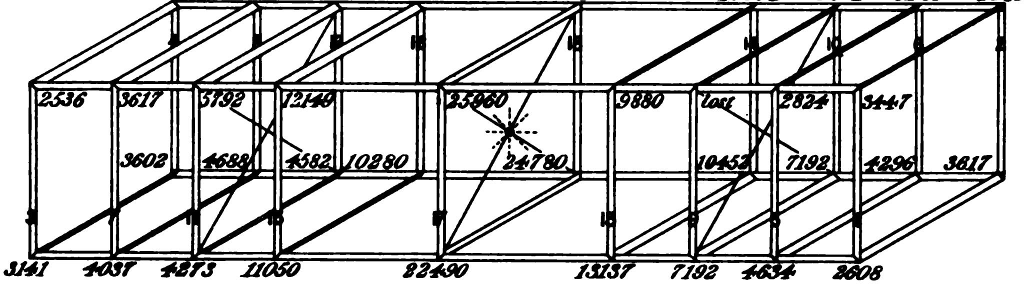
SHOT No. 398.
Charge, 40 lbs. Dynamite.
On Bottom.





SHOT No. 397.
Charge, 50 lbs. Dynamite.

SHOT No. 399.
Charge, 100 lbs. Dynamite.
On Bottom.



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Summary of experiments with dynamite No. 1—Continued.

CRATE SHOTS—Continued.

No. of shot.	Inclination of crate axis to horizon.	Charge.		Distance to gauges. (D)	Pressure per square inch. (P) (Mean of eight gauges.)			Remarks.
		Weight. (C)	Submergence. (S)		Observed.	Computed.	Difference.	
	°	*Pounds.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
226	0	10	42	20.7	1,138	998	+ 140	
343	0	10	42	20.7	960		− 38	
344	25	10	36	20.7	994		− 4	
345	25	10	36	20.7	1,090		+ 92	
226	0	10	42	25.5	646	746	− 100	
343	0	10	42	25.5	646		− 100	
344	25	10	36	25.5	858		+ 112	
345	25	10	36	25.5	668		− 78	
348	0	15	45	6.5	4,454	6,611	− 2,157	
348	0	15	45	11.8	2,356	2,872	− 516	
348	0	15	45	16.1	1,539	1,796	− 257	
348	0	15	45	20.7	1,325	1,309	+ 16	
348	0	15	45	25.5	847	977	− 130	
349	0	20	45	6.5	5,248	8,007	− 2,759	
349	0	20	45	11.8	3,275	3,495	− 220	
349	0	20	45	16.1	1,990	2,186	− 196	
349	0	20	45	20.7	1,499	1,584	− 85	
349	0	20	45	25.5	1,014	1,184	− 170	
396	0	30	32	6.5	8,383	10,493	− 2,110	
396	0	30	32	11.8	4,494	4,558	− 64	
396	0	30	32	16.1	2,900	3,455	− 555	
396	0	30	32	20.7	2,061	2,076	− 15	
396	0	30	32	25.5	1,557	1,551	+ 6	
398	0	40	14	6.5	12,870	12,715	+ 155	Crate on bottom.
398	0	40	14	11.8	7,146	5,524	+ 1,622	Do.
398	0	40	14	16.1	4,051	3,455	+ 596	Do.
398	0	40	14	20.7	3,000	2,516	+ 484	Do.
398	0	40	14	25.5	2,613	1,879	+ 734	Do.
397	0	50	30	6.5	12,241	14,753	− 2,512	
397	0	50	30	11.8	6,583	6,409	+ 174	
397	0	50	30	16.1	3,817	4,009	− 192	
397	0	50	30	20.7	2,814	2,919	− 105	
397	0	50	30	25.5	1,840	2,181	− 341	
399	0	100	8	6.5	24,752	23,415	+ 1,337	Crate on bottom.
399	0	100	8	11.8	10,481	10,175	+ 306	Do.
399	0	100	8	16.1	6,076	6,361	− 285	Do.
399	0	100	8	20.7	3,959	4,633	− 674	Do.
399	0	100	8	25.5	3,088	3,461	− 373	Do.
Arithmetical sums					218,081	237,103	31,122	

Thus far, in this analysis of experiments with explosive compounds, attention has been restricted to the means of all the gauges at like distances; which, since they were symmetrically placed with respect to a horizontal plane containing the charge, may be assumed to measure energies and pressures in that plane. Vertical angular displacements are now to be considered.

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The rings were so suspended that ϑ was 30° for gauges Nos. 5 and 6; 90° for gauges Nos. 3 and 4; and 150° for gauges Nos. 1 and 2. Rejecting all shots in which any lead was defective, the data comprise 8 shots in the 3-foot, 82 shots in the 4-foot, and 22 shots in the 5-foot ring. The 8-foot ring was so badly distorted by the strains to which it was subjected that no use should be made of the 14 shots fired in it for this discussion.

With very large charges it was not safe to suspend the crate otherwise than with the longitudinal axis horizontal, lest the increased shock should collapse the buoys; but with 5 and 10 pound charges six inclined shots were tried. Plates VI, VII, and IX exhibit the details and Plates XII and XIII an analysis of them.

The quantity K in equation (15), although a constant when attention is restricted to the horizontal plane containing the charge, becomes a function of the form $K = m(\vartheta + E)^t$ when the quantity ϑ varies. A careful study of the foregoing data by the graphical method showed that t is unity, giving the very simple expression:

$$K = m(\vartheta + E) \tag{18}$$

Combining this equation with equation (15), substituting the numerical values already deduced for A and q, and reducing, the following equation results, in which m and E are the only unknown quantities when W, D, C, and ϑ have been directly measured:

$$m\vartheta + mE = \frac{W(D + 0.01)^{2.1}}{C} \tag{19}$$

To determine the most probable values of the constants m and E, the method of least squares was applied to the data obtained in the rings and crate. The following table exhibits the mean numerical values of the second member of equation (19) for the indicated values of ϑ, as derived from all the data:

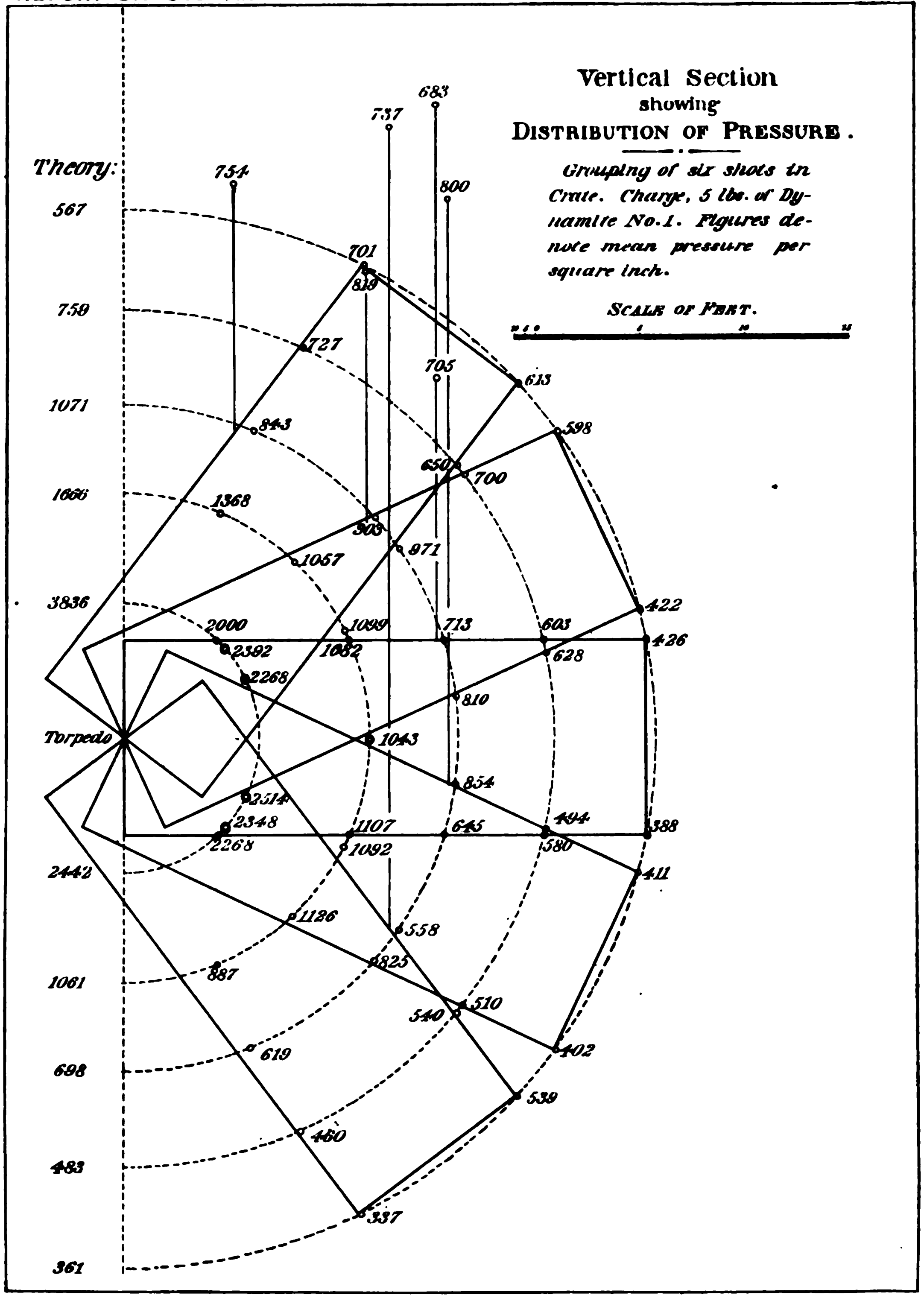
When $\vartheta = 30°$, second member of equation (19) $= 44.29$
When $\vartheta = 51°$, second member of equation (19) $= 49.02$
When $\vartheta = 78°$, second member of equation (19) $= 51.02$
When $\vartheta = 90°$, second member of equation (19) $= 52.79$
When $\vartheta = 102°$, second member of equation (19) $= 55.66$
When $\vartheta = 129°$, second member of equation (19) $= 63.81$
When $\vartheta = 150°$, second member of equation (19) $= 71.31$

These values gave seven equations of condition, from which the following normal equations were derived:

$$\begin{aligned} 67230\,m + 630\,mE - 37159 &= 0 \\ 630\,m + 7\,mE - 388 &= 0 \end{aligned}$$

Whence:

$$\begin{aligned} m &= 0.21 \\ mE &= 36.3 \end{aligned}$$



Vertical Section
showing
DISTRIBUTION OF PRESSURE.

Grouping of six shots in Crate. Charge, 5 lbs. of Dynamite No. 1. Figures denote mean pressure per square inch.

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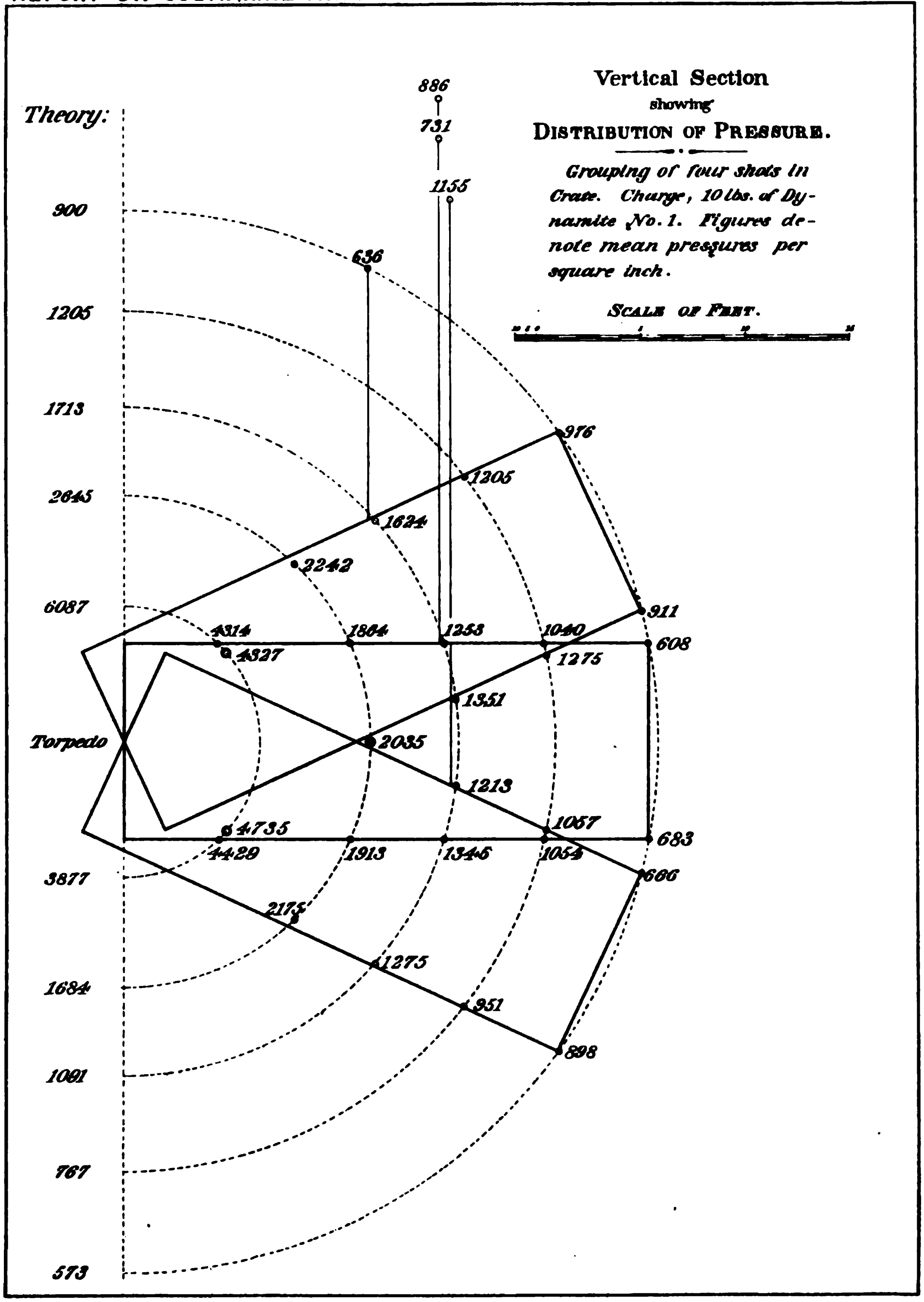

Vertical Section
showing
Distribution of Pressure.

Grouping of four shots in Crate. Charge, 10 lbs. of Dynamite No. 1. Figures denote mean pressures per square inch.

Scale of Feet.

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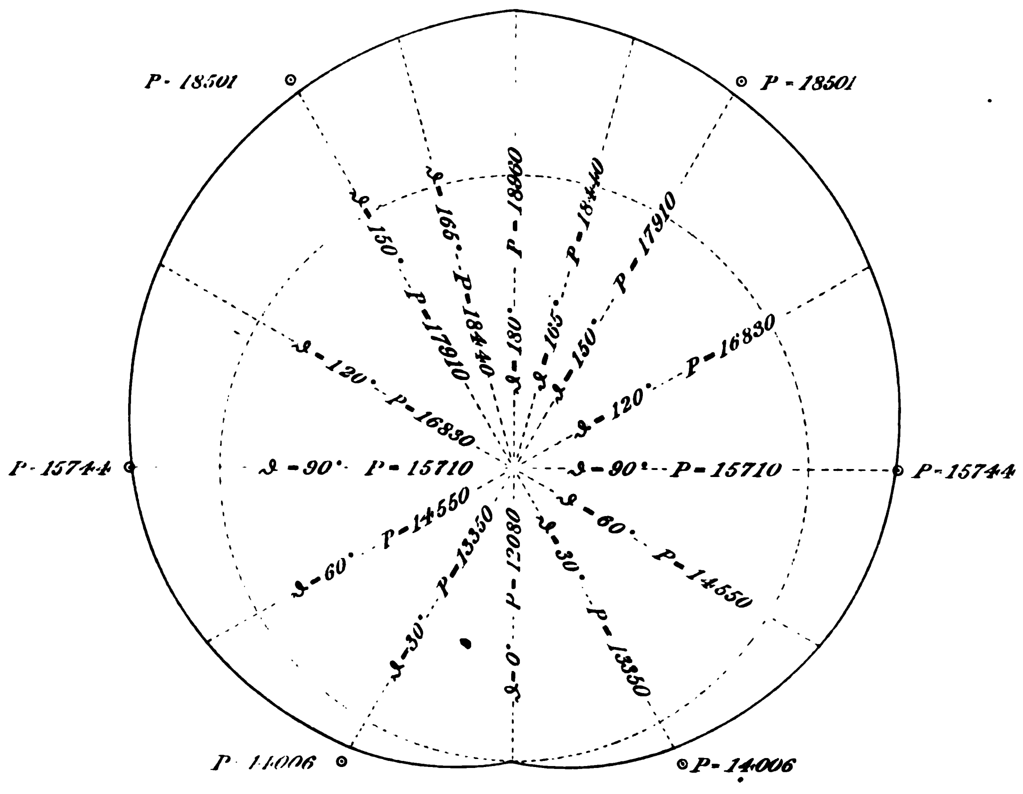

MEAN PRESSURES
in
VERTICAL PLANE.

Charge, 3 lbs. Dynamite No. 1, fired in 4 foot Ring. Theory shown by full line; observations by enclosed dots. Latter based on 180 records.

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It must be remembered that this value of *m* E depends solely upon the shots from which the above equations of condition were derived, and that a better determined value (because based upon much more extended data) may be found from the known numerical value (58) of K when ϑ is 90°. This bases the angular coefficient upon all the angular data, and the constant representing the particular explosive (in this case dynamite No. 1) upon all the shots fired with it in the rings and crate; thus:

$$0.21 \times 90^\circ + 0.21\ \mathrm{E} = 58$$

Whence *m* E becomes 39.1 for dynamite No. 1, giving:

$$\mathrm{E} = 186$$

$$\mathrm{K} = 0.21\ (\vartheta + 186) \tag{19}$$

Substituting this value of K in equation (15), the general formulæ for energy and mean pressure for dynamite No. 1 become:

$$\mathrm{W} = \frac{0.21\ (\vartheta + 186)\ \mathrm{C}}{(\mathrm{D} + 0.01)^{2.1}} \tag{20}$$

$$\mathrm{P} = \sqrt[3]{\left(\frac{6636\ (\vartheta + 186)\ \mathrm{C}}{(\mathrm{D} + 0.01)^{2.1}}\right)^2} \tag{21}$$

The comparison between the indications of equation (19) and the observations from which it was derived has been delayed, because it can be shown in a more intelligible form by making use of the last equation. This is done in the following tables. The change of *m* E from 36.3 to 39.1 increases, of course, the apparent discrepancies; but the accordance is still so satisfactory that the success of the analysis can hardly be questioned. Combined with the preceding tables it makes the weight of evidence in favor of these new formulæ all that could be expected in so difficult an investigation, dealing with forces so tremendous To exhibit the resulting law clearly to the eye Plate XIV has been prepared It shows both the general form of the curve of vertical angular intensity of action and the absolute difference between the theory and the means of 180 accurate observations.

Analysis of the vertical angular function.

DYNAMITE NO. 1; THREE-FOOT RING.

Charge.	No. of leads.	ϑ = 150°			ϑ = 90°			ϑ = 30°		
		Observed. (P)	Comp. (P)	Diff.	Observed. (P)	Comp. (P)	Diff.	Observed. (P)	Comp. (P)	Diff.
Pounds.		*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
0. 25	2	6, 389 ± 731	5, 706	+ 683	4, 650 ± 28	5, 006	− 356	4, 436 ± 116	4, 251	+ 185
1	4	15, 714 590	14, 383	+ 1, 331	12, 258 191	12, 615	− 357	10, 135 139	10, 742	− 607
2	6	21, 965 1, 121	22, 830	− 865	19, 144 378	20, 025	− 881	18, 076 441	17, 010	+ 1, 066
3	4	29, 775 1, 185	29, 915	− 140	26, 966 868	26, 235	+ 731	23, 743 971	22, 285	+ 1, 458
Means....		20, 408 ± 949	20, 349	888	17, 566 ± 410	17, 848	647	15, 735 ± 457	15, 167	939

Analysis of the vertical angular function—Continued.

DYNAMITE NO. 1; FOUR-FOOT RING.

Charge.	No. of leads.	$\vartheta = 150°$			$\vartheta = 90°$			$\vartheta = 30°$		
		Observed. (P)	Comp. (P)	Diff.	Observed. (P)	Comp. (P)	Diff.	Observed. (P)	Comp. (P)	Diff.
Pounds.		*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
0 50	52	5,245±100	5,425	− 180	4,804± 77	4,758	+ 46	4,058± 76	4,041	+ 17
1	30	9,595 300	8,612	+ 983	7,854 76	7,553	+ 301	6,785 246	6,415	+ 370
2	4	19,100 594	13,670	+ 5,430	12,394 379	11,990	+ 404	10,666 327	10,180	+ 486
3	60	18,528 280	17,910	+ 618	15,745 142	15,710	+ 35	14,007 137	13,350	+ 657
4	4	20,383 858	21,710	− 1,327	20,311 669	19,030	+ 1,281	18,128 236	16,160	+ 1,968
5	14	21,790 650	25,190	− 3,400	21,205 405	22,090	− 885	18,678 894	18,287	− 391
Means....		13,020±280	12,861	918	11,328±150	11,280	199	9,949±202	9,583	497

DYNAMITE NO. 1; FIVE-FOOT RING.

Charge.	No. of leads.	$\vartheta = 150°$			$\vartheta = 90°$			$\vartheta = 30°$		
		Observed. (P)	Comp. (P)	Diff.	Observed. (P)	Comp. (P)	Diff.	Observed. (P)	Comp. (P)	Diff.
1	8	6,398±141	5,921	+ 477	4,498±108	5,193	− 695	3,606±166	4,479	− 873
2	8	12,487 591	9,400	+ 3,087	7,759 186	8,244	− 485	6,263 184	7,110	− 847
3	8	14,071 385	12,317	+ 1,754	9,824 336	10,802	− 978	9,076 241	9,318	− 242
4	10	16,939 575	14,920	+ 2,019	11,526 153	13,090	− 1,564	11,067 300	11,290	− 223
5	10	14,021 385	17,313	− 3,292	12,046 254	15,190	− 3,144	12,787 270	13,100	− 313
Means....		13,028±421	12,351	2,174	9,372±206	10,834	1,462	8,866±237	9,344	478

In considering *individual* shots with explosive mixtures, it will be remembered that the intensity of action in different directions from the charge varied greatly, being apparently determined by the locus of the accidental yielding of the case, and the consequent direction of the initial burst of gas. With explosive compounds this tendency in general does not exhibit itself, as may easily be seen by comparing the indications of the different gauges in Appendices A and B. Sometimes, however, it does appear; and shot No. 293 is so remarkable an example that attention may well be drawn to it This shot, to which reference has already been made on page 71, was fired in the crate, and is exhibited to the eye on Plate V. By comparing the indications of top gauges, placed opposite but symmetrically with respect to the charge, it will be seen that the line of maximum intensity was by no means vertical, but inclined toward the 1–2 end of the crate at a very great angle. Eighteen different gauges agree in indicating that if two vessels had been situated at equal distances on opposite sides of a vertical transverse plane containing this charge, one would have received double the shock of the other. This effect is anomalous, and very rare with detonating explosives; but after so unmistakable an example, the *possibility* of its occurring should not be forgotten.

In order to compare the strength of dynamite No. 1 in sub-aqueous explosions with that of other explosive compounds, shots were fired with gun-cotton, dualin, nitro-glycerine, dynamite No. 2, mica powder, vulcan powder, rendrock, hercules powder, electric powder, Designolle powder, Brugere or picric powder, and explosive gelatine

As these are all detonating explosives they may be assumed to resemble dynamite No 1 sufficiently to be governed by the laws indicated in equation (16); and hence working equations for each of them may be deduced by finding the numerical values of K from the observations. This will now be done, before proceeding further with the study of dynamite No. 1.

Gun-cotton.—There were 66 charges of this explosive fired in the rings; but 32 of them were contained in wooden boxes, and for reasons already stated these are reserved for future consideration. This leaves 34 shots available for the present analysis; *i. e.*, about 200 gauge measurements.

These shots were divided between Abel compressed gun-cotton, dry, the same containing 25 per cent. of fresh water, and granulated gun-cotton wetted to a like extent, all made at Stowmarket, England.

The supply of the variety first named was imported in 1871, and consisted of cylindrical discs of two sizes, one being 3 inches in diameter and 1.75 inches in height, weighing half a pound, and the other 1 inch in diameter and 1 inch in height, weighing 0.5 ounce. Since that date, opinion in Europe appears to tend toward an increase of size for the torpedo service. Thus, in 1876 Russia had adopted cylinders 15 inches in diameter and 4.5 in height, weighing 25 pounds; France, slabs 4.75 by 4.75 by 1.6 inches, weighing 22 ounces; and England, slabs 6 by 6 by 1.75 inches, weighing 2.5 pounds. As no difference could be detected between the intensity of action of the two imported sizes when inclosed in a tight case under water, it has not been considered necessary to try the larger varieties. The only advantage claimed for them is that they render a closer packing possible within the torpedo, and hence, by reducing the air space, tend to cause a more sudden shock to the water. In rock blasting, experience has shown this to be an important matter, but the claim evidently can have no weight for buoyant mines, since the condition of flotation requires considerable air space inside the torpedo. The subject will be considered more fully hereafter.

For tests of compressed gun-cotton in a wet state, pure fresh water amounting to one-fourth of the weight of the charge was added to the dry discs on hand. The wet granulated gun-cotton was imported in 1876, and was used in the state in which it was received, evaporation having been guarded against by forwarding the material in closed rubber bags. The percentage of water was the same as above. The grains varied between mortar and cannon powder in size, but were more regular in form and more nearly spherical

The first point to determine is whether there be any difference in strength corresponding to these differences of condition which may render separate formulæ necessary.

This question is settled in the negative by the following table, which exhibts the results of a series of shots fired in the 4 foot ring under identical conditions. The total charge was 5 pounds (not including water); the dry primers weighed 1 pound, and were protected by oiled paper from moisture; the cases were tin cans No. 2 (water tight); the depth of water was 75 feet, and the submergence 34 feet; the pressures are each derived from six gauge measurements.

Gun-cotton.

FIVE-POUND CHARGES IN FOUR-FOOT RING.

Compressed, dry.		Compressed, wet.		Granulated, wet.	
No. of shot.	Observed pressure.	No. of shot.	Observed pressure.	No. of shot.	Observed pressure.
	Pounds.		*Pounds.*		*Pounds.*
257	18, 826	525	18, 453	532	19, 040
535	19, 618	526	17, 864	533	18, 506
536	18, 727	529	18, 374	527	18, 873
537	19, 662	530	18, 519	528	16, 807
538	17, 471	531	18, 564	534	18, 950
539	18, 867				
Mean..........	18, 862 ± 219	Mean..........	18, 355 ± 86	Mean..........	18, 435 ± 237

This table shows that there is no marked difference in strength between these varieties and conditions of gun-cotton, although the addition of water seems to cause a small loss of about 2 per cent. A single formula may therefore be framed, applicable to them indiscriminately.

The simplest method of deducing such a formula is the following, which, accordingly, has been adopted for this and other similar analyses.

The constants A and q in equation (15) may be assumed to remain so nearly constant for explosives of this class that the values found for them by the experiments with dynamite can be adopted. Hence:

$$(22) \qquad K = \frac{W\ (D + 0.01)^{2.1}}{C}$$

The numerical value of K for each observation is computed by this formula; and the mean of them, after the application of Peirce's Criterion for the rejection of doubtful observations, is adopted as the true value. The probable error is computed and reported as a measure of the accordance among the observations.

This process, applied to the 31 good shots with gun-cotton in thin cases, gave the following results, shots 402 and 412 being rejected by Peirce's Criterion:

For dry compressed (12 shots), $K = 48.63$
For wet compressed (5 shots), $K = 44.12$
For wet granulated (12 shots), $K = 47.60$
Average, gun-cotton (29 shots), $K = 47.28 \pm 0.65$

The latter value was adopted, giving (equations (15) and (6)) the following formulæ for the action of this explosive in the horizontal plane containing the charge:

$$(23) \qquad W = \frac{47.28\,C}{(D + 0.01)^{2.1}}$$

$$(24) \qquad P = \sqrt[3]{\left(\frac{1493000\,C}{(D + 0.01)^{2.1}}\right)^2}$$

The following table exhibits the data above discussed, with a comparison between the indications of these formulæ and the measurements. No better results could be desired in such an investigation, the discrepancies being no greater than the differences between the individual shots, while the absolute accordance is all that could reasonably be expected.

Summary of gun-cotton experiments.

THIN CASES.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
	Weight. (C)	Condition.			Observed.	Computed.	Difference.	
	Pounds.		*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
227	1.0	Dry compressed.	4	1.62	6,190	6,593	— 403	
400	1.6	Wet granulated.	4	1.62	10,409	9,019	+ 1,390	
412	1.6	Wet granulated.	4	1.62	11,225		+ 2,206	Rejected by Criterion.
417	2.0	Dry compressed.	4	1.62	11,075	10,465	+ 610	
418	2.0	Dry compressed.	4	1.62	11,288		+ 823	
228	2.0	Dry compressed.	4	1.62	11,661		+ 1,196	
415	2.0	Wet compressed.	4	1.62	2,110		....	2d order? Primer, 1.75 ounces.
416	2.0	Wet compressed.	4	1.62	1,694		....	Do.
403	2.4	Wet granulated.	4	1.62	12,106	11,815	+ 291	
411	2.4	Wet granulated.	4	1.62	13,240		+ 1,425	
401	2.4	Wet granulated.	4	1.62	11,299		— 516	
402	2.4	Wet granulated.	4	1.62	9,201		— 2,614	Rejected by Criterion.
229	3.0	Dry compressed.	4	1.62	14,992	13,713	+ 1,279	
404	3.2	Wet granulated.	4	1.62	12,916	14,316	— 1,400	
413	3.2	Wet granulated.	4	1.62	12,926		— 1,390	
230	4	Dry compressed.	4	1.62	16,953	16,613	+ 340	
419	4	Wet granulated.	4	1.62	17,740		+ 1,127	
414	4	Wet granulated.	4	1.62	13,136		....	2d order? Primer, 0.75 ounces.
257	5	Dry compressed.	4	1.62	18,826	19,285	— 459	
532	5	Wet granulated.	4	1.62	19,049		— 245	
533	5	Wet granulated.	4	1.62	18,506		— 779	
527	5	Wet granulated.	4	1.62	18,873		— 412	
528	5	Wet granulated.	4	1.62	16,807		— 2,478	
534	5	Wet granulated,	4	1.62	18,950		— 335	
525	5	Wet compressed.	4	1.62	18,435		— 850	
526	5	Wet compressed.	4	1.62	17,864		— 1,421	
529	5	Wet compressed.	4	1.62	18,374		— 911	
530	5	Wet compressed.	4	1.62	18,519		— 766	
531	5	Wet compressed.	4	1.62	18,564		— 721	
535	5	Dry compressed.	4	1.62	19,618		+ 333	
536	5	Dry compressed.	4	1.62	18,727		— 588	
537	5	Dry compressed.	4	1.62	19,662		+ 377	
538	5	Dry compressed.	4	1.62	17,471		— 1,814	
539	5	Dry compressed.	4	1.62	18,867		— 418	
Arithmetical means					15,494	15,755	964	

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The vertical angular function is next to be considered. The general expression for this function, as already explained, is the following:

$$K = m\,(\vartheta + E) \tag{18}$$

If the data for the other explosive compounds were as numerous as for dynamite the proper method would be to discuss each of them in the manner adopted for the latter. As, however, it may reasonably be assumed that *m* is constant for this whole class, it appears better to adopt the value already found, based on so many and extended experiments, rather than to rest its determination on a few shots. The ultimate test—the accordance between the observations and the formula—will show whether this be the true method. Hence, for gun-cotton:

$$K = 47.28 = 0.21\,(\vartheta + E)$$

$$E = 135$$

$$P = \sqrt[3]{\left(\frac{6636\,(\vartheta + 135)\,C}{(D + 0.01)^{2.1}}\right)^2} \tag{25}$$

The following table exhibits the application of this formula to all the data for gun-cotton exploded in thin cases in which no leads were defective:

Analysis of the vertical angular function.

GUN-COTTON IN FOUR-FOOT RING.

Charge.	No. of leads.	$\vartheta = 150°$			$\vartheta = 90°$			$\vartheta = 30°$		
		Observed. (P)	Comp. (P)	Diff.	Observed. (P)	Comp. (P)	Diff.	Observed. (P)	Comp. (P)	Diff.
Pounds		*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	2	6,625 ± 116	7,718	− 1,093	5,445 ± 333	6,593	− 1,149	6,500 ± 318	5,360	+ 1,140
1.6	2	13,111 627	11,157	+ 1,954	10,157 774	9,019	+ 1,138	7,958 82	7,333	+ 625
2	6	11,807 463	12,250	− 443	12,186 96	10,465	+ 1,721	10,031 91	8,510	+ 1,521
2.4	6	13,112 620	13,825	− 713	11,224 150	11,815	− 591	9,405 184	9,610	− 205
3	2	16,408 1,171	16,053	+ 355	14,534 509	13,713	+ 821	13,533 520	11,153	+ 2,380
3.2	4	13,692 369	16,753	− 3,061	13,690 493	14,316	− 626	11,375 179	11,637	− 262
4	6	18,447 704	19,445	− 998	16,441 426	16,613	− 172	12,941 1,083	13,510	− 569
5	30	19,208 218	22,560	− 3,352	19,800 280	19,285	+ 515	16,641 147	15,680	+ 961
Means....		16,612 ± 389	18,738	2,285	16,347 ± 449	15,997	674	13,706 ± 261	12,973	895

Remembering that this is an absolute test of the whole formula, and not simply a relative test of the value found for the angular function, the accordance is surprisingly close. Indeed, the analysis corrects what is palpably a deficiency in the indications of the two upper gauges ($\vartheta = 150°$), due probably to some of the pistons being slightly jammed by the intensity of the shocks of the larger charges.

Dualin.—This explosive, invented by Mr. Carl Dittmar, differs from dynamite No. 1 in the material used as an absorbent, being claimed by the inventor to consist of "cellulose, nitro-cellulose, nitro-starch, nitro-mannite, and nitro-glycerine mixed in different combinations, depending upon the degree of strength which it is desired the powder should possess in adapting its use to various purposes." In its best form it is believed to consist of nitro-glycerine absorbed by Schultze's powder—nitrated cellulose obtained by treating woody fibre with mixed nitric and sulphuric acids. Analyses of the manufactured article as sold in the market are claimed to have shown that the absorbent is simple sawdust not nitrated. Variations in the method of manufacture are certainly frequent, causing differences in the article as furnished. The experiments here reported were made with a sample lot purchased in August, 1871, specially for these trials, as was understood at the time by the maker, Mr. Dittmar; and there are several reasons to suppose that a quality more carefully prepared, and stronger than is usually to be had in trade, was supplied.

Neglecting, for the present, several shots fired in wooden boxes, 36 experiments were available for the general discussion—all made in the rings. The following table exhibits the data in full; and, for comparison, the indications given by the formulæ deduced below:

Summary of dualin experiments.

RING SHOTS.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
157	1	35	3	1. 12	17, 153	13, 976	+ 3, 177	Doubtful.
132	1	35	4	1. 62	9, 833	8, 372	+ 1, 461	
232	1	35	4	1. 62	8, 627		+ 255	
144	1	35	5	2. 12	5, 772	5, 755	+ 17	
158	2	35	3	1. 12	23, 701	22, 195	+ 1, 506	Doubtful.
133	2	35	4	1. 62	14, 524	13, 290	+ 1, 234	
233	2	35	4	1. 62	12, 970		− 320	
145	2	35	5	2. 12	9, 037	9, 138	− 101	
167	3	35	3	1. 13	22, 288	29, 080	− 6, 792	Pistons jammed.
124	3	35	4	1. 62	16, 784	17, 417	− 633	
231	3	35	4	1. 62	17, 262		− 155	
234	3	35	4	1. 62	15, 911		− 1, 506	
239	3	6	4	1. 62	18, 881		+ 1, 464	
240	3	6	4	1. 62	17, 090		− 327	
241	3	6	4	1. 62	17, 324		− 93	
242	3	6	4	1. 62	20, 253		+ 2, 836	
243	3	6	4	1. 62	13, 965		− 3, 452	
244	3	6	4	1. 62	17, 644		+ 227	
245	3	6	4	1. 62	16, 708		− 709	
246	3	6	4	1. 62	17, 101		− 316	
247	3	6	4	1. 62	17, 934		+ 517	
248	3	6	4	1. 62	16, 232		+ 1, 185	
249	3	6	4	1. 62	19, 849		+ 2, 266	

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Summary of dualin experiments—Continued.

RING SHOTS—Continued.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
250	3	6	4	1.62	18,827		+ 1,410	
251	3	6	4	1.62	15,655		− 1,762	
252	3	6	4	1.62	17,036		− 381	
258	3	6	4	1.62	16,088		− 1,329	
259	3	6	4	1.62	17,975		+ 558	
261	3	6	4	1.62	16,490		− 927	
262	3	6	4	1.62	16,390		− 1,027	
260	3	0	4	1.62	9,198		....	Charge awash.
151	3	35	5	2.12	12,462	11,972	+ 490	
168	4	35	3	1.12	24,015	35,220	−11,105	Pistons jammed.
117	4	35	4	1.62	20,869	21,097	− 228	
236	4	35	4	1.62	19,268		− 1,829	
153	4	35	5	2.12	12,692	14,500	− 1,808	
256	5	35	4	1.62	20,618	24,495	− 3,877	
Arithmetical means					16,528	17,155	1,565	

This explosive was so powerful that the gauges of the 3-foot ring were more or less affected by the jamming of the pistons, and they were not used in deducing K. This based the determination upon 32 shots, or about 192 gauge records. The method of analysis already explained for gun-cotton was employed, giving K = 67.70 ± 1.08, no observation being thrown out by Peirce's Criterion. Hence, for the horizontal plane containing the charge:

$$(26) \qquad W = \frac{67.7\ C}{(D + 0.01)^{2.1}}$$

$$(27) \qquad P = \sqrt[3]{\left(\frac{2137000\ C}{(D + 0.01)^{2.1}}\right)^2}$$

The analysis of the vertical angular function was made in the manner already explained for gun-cotton, giving E = 232. Hence, for the general dualin formula:

$$(28) \qquad P = \sqrt[3]{\left(\frac{6636\ (S + 232)\ C}{(D + 0.01)^{2.1}}\right)^2}$$

The following tables give a comparison between the observations and the indications of this formula. The accordance is surprisingly close; and, combined with the gun-cotton study, is quite sufficient to establish the correctness of my general method of analysis, which, it will be remembered, is based upon the assumption that one and the same general formula should apply to all the explosive compounds, when the individual value of E (in this case 232) is known.

Analysis of the vertical angular function.

DUALIN, IN FOUR-FOOT RING.

Charge.	No. of leads.	ϑ = 150°			ϑ = 90°			ϑ = 30°		
		Observed. (P)	Comp. (P)	Diff.	Observed. (P)	Comp. (P)	Diff.	Observed. (P)	Comp. (P)	Diff.
Pounds.		*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1	4	11,778 ± 683	9,382	+ 2,396	8,832 ± 375	8,372	+ 460	7,079 ± 534	7,296	— 217
2	4	15,502 412	14,893	+ 609	13,845 592	13,290	+ 554	11,896 352	11,580	+ 316
3	34	17,190 301	19,515	— 2,325	18,082 251	17,417	+ 665	15,387 328	15,175	+ 212
4	4	20,427 1,161	23,645	— 3,218	20,188 645	21,097	— 909	19,590 187	18,385	+ 1,205
5	2	23,275 1,042	27,430	— 4,155	22,893 785	24,495	— 1,602	15,671 480	21,335	— 5,664
Means . . .		17,122 ± 445	18,939	2,339	17,333 ± 345	16,921	698	14,766 ± 342	14,743	581

DUALIN, IN FIVE-FOOT RING.

Charge.	No. of leads.	ϑ = 150° Observed. (P)	ϑ = 150° Comp. (P)	ϑ = 150° Diff.	ϑ = 90° Observed. (P)	ϑ = 90° Comp. (P)	ϑ = 90° Diff.	ϑ = 30° Observed. (P)	ϑ = 30° Comp. (P)	ϑ = 30° Diff.
1	2	6,587 ± 536	6,450	+ 137	5,704 ± 965	5,755	— 51	5,026 ± 250	5,017	+ 9
4	2	15,147 650	16,257	— 1,110	13,543 1,071	14,500	— 957	9,388 1,464	12,640	— 3,252
Means . . .		10,867 ± 593	11,353	624	9,624 ± 1,018	10,127	504	7,207 ± 857	8,828	1,630

Lithofracteur (or Rendrock).—The precise composition of this explosive, as devised and manufactured by Messrs. G. Krebs & Co., of Cologne, is not officially stated. As roughly indicated by them, it consists of:

Nitro-glycerine	525
Silica	225
Mineral bodies	250

According to Lieutenant Trauzl, of the Austrian engineers, it consists of:

Nitro-glycerine	52
Kieselguhr	30
Powdered coal	12
Sodium nitrate	4
Sulphur	2

This explosive, or what purports to be a modified form of the same, has been introduced into this country by Mr. T. S. Beach, under the name of rendrock. His combination, as sold in the market, closely resembles caked gunpowder in appearance, and, according to the terms of his patent, is the following, but he declined to state specifically the ingredients:

Nitro-glycerine	40
Sodium or potassium nitrate	40
Cellulose	13
Paraffine	7

For these trials he supplied two additional samples of his powder, containing respectively 20 and 60 per cent of nitro-glycerine. The latter was decidedly too moist to be safe for general use, and the deliquescent nature of the absorbent caused exudation even in the trade article when exposed to dampness.

Ten shots were fired with the composition as usually supplied by Mr. Beach, and five with each of the other samples, thus basing the determination on 120 gauge measurements in the 4-foot and 5-foot rings. These data, subjected to the analysis explained for gun-cotton, gave the following results, no shot being thrown out by Peirce's Criterion:

For $\frac{20}{100}$ nitro-glycerine sample; $K = 40.06 \pm 2.89$
For $\frac{40}{100}$ nitro-glycerine sample; $K = 52.56 \pm 2.19$
For $\frac{60}{100}$ nitro-glycerine sample; $K = 53\ 78 \pm 2.93$

The following table exhibits these data, and a comparison between the measurements and the formulæ:

Summary of rendrock experiments.

TWENTY PER CENT. NITRO-GLYCERINE.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
315	1	35	4	1.62	6,133	5,908	+ 225	
318	2	35	4	1.62	10,983	9,380	+ 1,603	
322	3	35	5	2.12	8,533	8,450	+ 83	
325	4	35	5	2.12	8,418	10,140	− 1,722	
328	5	35	5	2.12	10,076	11,880	− 1,804	
Arithmetical means					8,829	9,152	1,087	
FORTY PER CENT. NITRO-GLYCERINE.								
316	1	35	4	1.62	8,120	7,072	+ 1,048	
333	1	35	4	1.62	7,545		+ 473	
319	2	35	4	1.62	8,633	......	....	Broke ring. Rejected.
336	2	35	4	1.62	12,809	11,223	+ 586	
320	2	35	5	2.12	6,834	7,718	− 884	
338	3	35	4	1.62	13,732	14,707	− 975	
323	3	35	5	2.12	10,673	10,115	+ 558	
340	4	35	4	1.62	15,226	17,817	− 2,591	
326	4	35	5	2.12	10,817	12,253	− 1,336	
342	5	35	4	1.62	16,977	20,675	− 3,698	
329	5	35	5	2.12	15,303	14,217	+ 1,086	
Arithmetical means					11,804	12,287	1,324	
SIXTY PER CENT. NITRO-GLYCERINE.								
317	1	35	4	1.62	8,416	7,183	+ 1,233	
321	2	35	5	2.12	7,052	7,840	− 788	
324	3	35	5	2.12	10,549	10,270	+ 279	
327	4	35	5	2.12	11,559	12,450	− 891	
330	5	35	5	2.12	13,508	14,443	− 935	
Arithmetical means					10,217	10,437	825	

From the foregoing values of K the following formulæ may be derived, by the process already explained for gun-cotton:

For $\frac{20}{100}$ nitro-glycerine sample; $P = \sqrt[3]{\left(\frac{663 ; (S + 101)\, C}{(D + 0.01)^{2.1}}\right)^2}$

(29) For $\frac{40}{100}$ nitro-glycerine sample; $P = \sqrt[3]{\left(\frac{6636\,(S + 160)\,C}{(D + 0.01)^{2.1}}\right)^2}$

For $\frac{60}{100}$ nitro-glycerine sample; $P = \sqrt[3]{\left(\frac{6636\,(S + 166)\,C}{(D + 0.01)^{2.1}}\right)^2}$

This discussion shows conclusively that the proportions of the different ingredients of the trade article are well chosen—at least for use under water; and that, so far as strength is concerned, rendrock has a high value for this kind of work as compared with many of the others, including gun-cotton.

Dynamite (or Giant Powder) No. 2.—This explosive, invented by Nobel, is based upon the idea of using gunpowder instead of the inert substance kieselguhr as the absorbent for the nitro-glycerine. As supplied by the Atlantic Giant Powder Company its composition is the following:

Nitro-glycerine	36
Potassium or sodium nitrate	48
Sulphur	8
Resin, powdered coal, or charcoal	8

Nine shots, giving 54 gauge records, were fired with this explosive in the 4-foot ring. After the rejection of two of them by Peirce's Criterion the usual analysis gave:

$$K = 44.15 \pm 1.30$$

$$P = \sqrt[3]{\left(\frac{6636\,(S + 120)\,C}{(D + 0.01)^{2.1}}\right)^2} \qquad (30)$$

The following table exhibits the data, with a comparison between the measurements and formula:

Summary of experiments with dynamite No. 2.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
210	1	35	4	1.62	4,137	6,294	− 2,157	Rejected by Criterion.
334	1	35	4	1.62	7,032		+ 638	
350	1	35	4	1.62	5,900		− 394	
335	2	35	4	1.62	11,007	9,992	+ 1,015	
212	3	35	4	1.62	13,004	13,095	− 91	
337	3	35	4	1.62	13,367	13,095	+ 272	
339	4	35	4	1.62	14,168	15,860	− 1,692	
351	4	35	4	1.62	14,763		− 1,097	
341	5	35	4	1.62	17,626	18,410	+ 784	
Arithmetical means					11,223	11,688	904	

Vulcan Powder.—This explosive, supplied by Mr. R. W. Warren, belongs to the same class as dynamite No. 2.

It was tested by General Newton for rock blasting at Hallett's Point, with good results. The usual trade composition is the following; but Mr. Warren also sent for trial a sample marked No. 2, containing 5 per cent. more nitro-glycerine:

Nitro-glycerine	300
Sodium nitrate	525
Charcoal	105
Sulphur	70

Twenty shots—ten with each variety—were fired with this explosive in the 4-foot ring, giving 120 gauge records. Peirce's Criterion rejected one of them, and the usual analysis gave the following results for the tradė article:

$$K = 39.74 \pm 0.73$$

$$P = \sqrt[3]{\left(\frac{6636\ (S + 99)\ C}{(D + 0.01)^{2.1}}\right)^2} \qquad (31)$$

For the sample marked No. 2 (5 per cent. more nitro-glycerine):

$$K = 42.82 \pm 1.23$$

$$P = \sqrt[3]{\left(\frac{6636\ (S + 114)\ C}{(D + 0.01)^{2.1}}\right)^2}$$

The following table exhibits the data, and a comparison between the measurements and formulæ:

Summary of experiments with vulcan powder No. 1.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
429	1	35	4	1. 62	6, 717	5, 868	+ 849	Rejected by Criterion.
430	1	35	4	1. 62	6, 378		+ 510	
431	2	35	4	1. 62	9, 825	9, 316	+ 509	
432	2	35	4	1. 62	9, 236		— 80	
433	3	35	4	1. 62	12, 410	12, 207	+ 203	
434	3	35	4	1. 62	12, 198		— 9	
435	4	35	4	1. 62	14, 029	14, 787	— 758	
436	4	35	4	1. 62	13, 769		— 1, 018	
437	5	35	4	1. 62	17, 217	17, 160	+ 57	
438	5	35	4	1. 62	15, 937		— 1, 223	
	Arithmetical means				11, 772	11, 868	522	

Summary of experiments with vulcan powder No. 2.

439	1	35	4	1. 62	6, 481	6, 174	+ 307	
441	1	35	4	1. 62	7, 066		+ 892	
442	2	35	4	1. 62	10, 232	9, 802	+ 430	
443	2	35	4	1. 62	10, 495		+ 693	
444	3	35	4	1. 62	12, 875	12, 823	+ 52	
445	3	35	4	1. 62	12, 700		— 123	
446	4	35	4	1. 62	13, 619	15, 560	— 1, 941	
447	4	35	4	1. 62	14, 301		— 1, 259	
440	5	35	4	1. 62	17, 142	18, 335	— 1, 193	
448	5	35	4	1. 62	16, 158		— 2, 177	
	Arithmetical means				12, 107	12, 539	907	

Mica Powder.—This explosive, made by Mr. G. M. Mowbray, consists of finely divided mica scales (a non-absorbent silicate of alumina), and tri-nitro-glycerine ($C_6 H_5 O_3 3NO_5$), mixed commonly in the proportion of 475 parts by weight of the former to 525 parts of the latter. It was largely used in completing the Hoosac Tunnel, with good results.

The nitro-glycerine adheres to and coats the scales, but is not absorbed by them; and Mr. Mowbray claims that, by thus exposing an immense surface of nitro-glycerine to the initial heat and vibration developed by the fuze, a more instantaneous reaction is secured than with the nitro-glycerine in a liquid form. He estimates the interstitial spaces through which the flame penetrates at one-fourth the volume of the powder when tolerably well rammed

As will hereafter appear my experiments have tended indirectly to confirm this idea of Mr. Mowbray respecting the relative time of the explosive reactions of these two substances, which is also fully endorsed by Prof. Henry Morton in his testimony in the suit of the Atlantic Giant Powder Company *vs.* G. M. Mowbry *et al.*, filed before the circuit court of the United States, district of Massachusetts, in 1875. In sub-aqueous explosions, however, the practical effect of the difference is precisely the reverse of that which they discovered when experimenting in strongly resisting media. This by no means militates against the correctness of their results, for, as already stated, the nature of the resistance offered to the expansion of the gases modifies the effect of the time element. A yielding surface requires a more sustained impulse, within certain limits, than one whose rigidity causes instantaneous fracture.

Mr. Mowbray supplied two samples of mica powder for trial, No. 1 containing 52 per cent., and No. 2 40 per cent. of nitro-glycerine. Nineteen shots were fired in the 4-foot ring, giving 114 gauge measurements. Discussed in the usual manner, none of the shots being rejected by Peirce's Criterion, they give the following values of K:

Mica powder No. 1; $K = 43.86 \pm 0.79$
Mica powder No. 2; $K = 28.61 \pm 1.03$

Hence:

(32) Mica powder No. 1; $$P = \sqrt[3]{\left(\frac{6636\,(\vartheta + 119)\,C}{(D + 0.01)^{2.1}}\right)^2}$$

(33) Mica powder No. 2; $$P = \sqrt[3]{\left(\frac{6636\,(\vartheta + 46)\,C}{(C + 0.01)^{2.1}}\right)^2}$$

The following tables exhibit the data upon which these formulæ are based, and the accordance between the observations and the computed mean pressures, which it will be noticed is remarkably close:

Summary of experiments with mica powder No. 1.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
378	1	35	4	1. 62	6, 309	6, 274	+ 35	
379	2	35	4	1. 62	10, 552	9, 960	+ 590	
380	3	35	4	1. 62	13, 035	13, 053	+ 18	
384	4	35	4	1. 62	15, 862	15, 810	+ 52	
385	4	35	4	1. 62	14, 761		— 1, 049	
386	5	35	4	1. 62	17, 776	18, 347	— 571	
Arithmetical means					13, 049	13, 209	463	

Summary of experiments with mica powder No. 2.

352	1	35	4	1. 62	3, 855	4, 712	— 857	
362	1	35	4	1. 62	4, 287		— 425	
353	2	35	4	1. 62	7, 913	7, 480	+ 433	
363	2	35	4	1. 62	7, 348		— 132	
354	3	35	4	1. 62	10, 099	9, 802	+ 297	
364	3	35	4	1. 62	11, 781		+ 1, 979	
355	4	35	4	1. 62	13, 084	11, 872	+ 1, 212	
365	4	35	4	1. 62	12, 849		+ 977	
381	4	35	4	1. 62	13, 476		+ 1, 604	
356	5	35	4	1. 62	11, 192	13, 777	— 2, 585	
366	5	35	4	1. 62	12, 281		— 1, 496	
382	5	35	4	1. 62	12, 731		— 1, 046	
383	5	35	4	1. 62	12, 363		— 1, 414	
Arithmetical means					10, 251	10, 286	1, 112	

Nitro-glycerine.—For reasons which will appear hereafter in discussing these formulæ it became desirable to determine whether nitro-glycerine, as it is found in the market, can be considered to be uniform in respect to intensity of action; *i. e.*, whether the chemical differences which exist between mono-, di-, and tri-nitro-glycerine affect the strength of the explosive as practically used. That such is the case has been advanced and stoutly maintained by parties interested in the different processes and modes of manufacture.

It will be noticed that this question is quite different from that of relative safety of manipulation, respecting which there can be no difference of opinion. An article carefully made and properly treated can be kept on hand for an indefinite period, while neglect in the needful precautions insures rapid deterioration, ending sometimes in spontaneous explosion and sometimes in the loss of all explosive properties.

To test this question practically supplies were obtained in 1871–'72 from three parties, Messrs. Marcelin & Warren, who were then supplying General Newton with large quantities for immediate use in rock blasting in New York Harbor; from Mr. G. M. Mowbray, who was furnishing the Hoosac Tunnel with a very superior article; and from Mr. Charles T. Chester, who had a manufactory upon the Hudson.

The Marcelin & Warren sample was tested immediately after the manufacture, in the milky condition in which it was used by General Newton. Mr. Mowbray sent his sample in a frozen state, thoroughly purified and fit for long storage. Mr. Chester delivered an article which had lost its milky appearance, but which was highly colored, contained free acid, and was evidently liable to give trouble if not carefully watched. It was kept in store for a couple of months, and occasionally tested in the rings. Although frequently supplied with fresh water, and treated with every care in storage, it gradually deteriorated, becoming weaker and less explosive until finally consumed.

Twenty-two shots were fired with these different samples in the 3-foot and 4-foot rings, giving 132 gauge measurements. Throwing out the last four shots with the Chester sample, which were affected by a very evident deterioration, no difference could be detected in the intensity of action developed in the rings. One formula represented them all fairly, although the explosive seems somewhat variable.

The analysis was made by the usual method, one shot (No. 92, Mowbray's) being rejected by Peirce's Criterion. The value of K was found to be:

$$K = 42.20 \pm 1.51$$

Hence:

$$(34) \qquad P = \sqrt[3]{\left(\frac{6636\,(\vartheta + 111)\,C}{(D + 0.01)^{2.1}}\right)^2}$$

The table exhibits the data and the corresponding indications of this formula. The gradual deterioration of Mr. Chester's sample is plainly shown by the figures—one shot (No. 253) which had been kept on hand 56 days failed altogether to explode, although a very powerful fuze was fired in it. Unquestionably, Mr. Mowbray's was the best sample; but since it exhibited no superiority in intensity of action, I infer that, so far as strength is concerned, his process has no advantage over less perfect methods of manufacture. For safety of handling and storage, beyond a doubt his product was immensely superior to those supplied by the other parties.

Summary of experiments with nitro-glycerine.

No. of shot.	Maker.	Date of test.	Charge. (C)	Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
						Obs'd.	Comp.	Diff.	
			Pounds.	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
75	Marcelin & Warren.........	Sept. 18, 1871	1	3	1. 12	12, 093	10, 212	+ 1, 881	Received September 16, 1871.
76	......do	... .do	2	3	1. 12	14, 815	16, 207	— 1, 392	
77	......do	.....do	3	3	1. 12	19, 311	21, 225	— 1, 914	
204	Chester....................	Sept. 9, 1872	2	4	1. 62	10, 197	9, 705	+ 492	Received September 9, 1872.
205	......do	.....do	3	4	1. 62	13, 548	12, 737	+ 811	
206	......do	Sept. 11, 1872	1	4	1. 62	7, 244	6, 114	+ 1, 130	
207	......do	.... do	2	4	1. 62	9, 155	9, 705	— 550	
208	......do	.....do	5	4	1. 62	22, 268	17, 878	+ 4, 390	

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Summary of experiments with nitro-glycerine—Continued.

No. of shot.	Maker.	Date of test.	Charge. (C)	Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
						Obs'd.	Comp.	Diff.	
			Pounds.	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
215	Chester	Sept. 11, 1872	4	4	1.62	14,758	15,407	− 649	
219	do	Sept. 30, 1872	1.25	3	1.12	13,879	11,847	+ 2,032	Dregs of case.
220	do	do	1	3	1.12	10,094	10,212	− 118	
221	do	do	2	3	1.12	12,416	16,207	− 3,791	
232	do	do	3	3	1.12	17,323	21,225	− 3,902	
237	do	Nov. 1, 1872	3	4	1.62	6,341	12,737	−......	Deteriorated.
238	do	do	3.60	4	1.62	6,486	14,363	−......	Deteriorated.
253	do	Nov. 4, 1872	2.40	4	1.62	......	......	......	Failed to explode.
254	do	do	2.40	4	1.62	7,219	10,957	−......	Deteriorated.
91	Mowbray	Sept. 30, 1871	1.75	4	1.62	8,855	8,878	− 23	Received September 29, 1871.
92	do	do	1	4	1.62	3,229	6,114	− 2,885	Rejected by Criterion.
93	do	do	2	4	1.62	8,582	9,705	− 1,123	
94	do	do	3	4	1.62	12,395	12,737	− 342	
95	do	do	4	4	1.62	11,883	15,407	− 3,524	
	Arithmetical means, omitting the three deteriorated shots					12,336	12,862	1,719	

Hercules Powder.—This explosive, supplied by the California Powder Works (San Francisco, Cal., and Cleveland, Ohio), belongs to the general class of the dynamites. It is sold in two grades, No. 1 XX and No. 2. The composition of No. 1 XX, which is decidedly overcharged with nitro-glycerine for safe handling in the military service, is the following:

Nitro-glycerine	77
Magnesium carbonate	20
Wood pulp	2
Sodium nitrate	1

That of No. 2 is the following:

Nitro-glycerine	420
Sodium nitrate	435
Wood pulp	110
Magnesium carbonate	35

Twenty-eight shots were fired with Hercules powder in the 4-foot and 5-foot rings, but as the records of one of the former were lost (with the ring), only twenty-seven are available.

Of these shots thirteen were with No. 1, giving 78 gauge records. Two shots were rejected by Peirce's Criterion, and the usual analysis gave the following results for this grade of the powder:

$$K = 63.17 \pm 1.14$$

$$P = \sqrt[3]{\left(\frac{6636\,(\vartheta + 211)\,C}{(D + 0.01)^{2.1}}\right)^2} \qquad (34a)$$

Fourteen shots were fired with grade No. 2, giving 88 gauge records. Peirce's Criterion rejected one shot, and the usual analysis resulted as follows:

$$K = 43.7 \pm 1.26$$

$$P = \sqrt[3]{\left(\frac{6636\,(S + 118)\,C}{(D + 0.01)^{2.1}}\right)^2} \qquad (34b)$$

The following tables exhibit these data, and a comparison between the measurements and the indications of the formulæ:

Summary of experiments with Hercules powder No. 1.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
550	1	33	4	1.62	10,941	8,004	+ 2,937	Rejected by Criterion.
551	1	33	4	1.62	10,273		+ 2,269	Do.
552	2	33	4	1.62	14,396	12,710	+ 1,686	
553	2	33	4	1.62	13,151		+ 441	
554	3	33	4	1.62	17,004	16,650	+ 354	
555	3	33	4	1.62	......		....	Lost ring.
556	4	34	5	2.12	13,900	13,865	+ 35	
557	4	34	5	2.12	14,342		+ 447	
564	4	34	5	2.12	12,904		− 961	
558	5	34	5	2.12	15,967	16,110	− 143	
559	5	34	5	2.12	16,027		− 83	
565	5	34	5	2.12	15,046		− 1,064	
566	5	34	5	2.12	15,266		− 844	
567	5	34	5	2.12	14,957		− 1,153	
Arithmetical means					14,167	13,864	957	
Summary of experiments with Hercules powder No. 2.								
540	1	33	4	1.62	7,078	6,256	+ 822	
541	1	33	4	1.62	7,390		+ 1,134	
542	2	33	4	1.62	12,649	9,931	+ 2,718	Rejected by Criterion.
543	2	33	4	1.62	11,549		+ 1,618	
544	3	33	4	1.62	12,985	13,020	− 35	
545	3	33	4	1.62	12,317		− 703	
546	4	33	4	1.62	14,029	15,760	− 1,731	
547	4	33	4	1.62	14,575		− 1,185	
548	5	33	4	1.62	17,063	18,290	− 1,227	
549	5	33	4	1.62	17,698		− 592	
560	4	34	5	2.12	10,493	11,610	− 1,117	
561	5	34	5	2.12	11,812	13,480	− 1,668	
562	5	34	5	2.12	11,293		− 2,187	
563	5	34	5	2.12	11,937		− 1,543	
Arithmetical means					12,348	12,755	1,306	

Electric Powder.—This explosive, supplied by Mr. N. M. Barney, of Titusville, Pa., is a nitro-glycerine compound with an explosive base. Two grades were tested—No. 1 containing 33 per cent. of nitro-glycerine, and No. 2, 28 per cent. The composition of the explosive base was communicated confidentially, and cannot therefore be stated; but it may be remarked that neither grade exhibited a tendency to deliquesce when exposed for a few days to damp air.

The powder is usually supplied in the form of cartridges—diameter to suit purchasers; and, in the circulars describing its use, great stress is laid upon the necessity of tamping with wet clay or water when the object is the removal of stumps or the blasting of loose boulders.

The nitro-glycerine is made under the patents of E. A. L. Roberts, a large manufacturer and the inventor of an "oil-well torpedo."

Twenty-six shots were fired with electric powder in the 4-foot ring; and, when analyzed in the usual manner, none were rejected by Peirce's Criterion. One charge, however, was accidentally wetted, and as its strength was greatly reduced thereby it was thrown out in framing the formulæ.

The data for grade No. 1 accordingly consisted of 13 shots, giving 78 gauge records, and for grade No. 2, of 12 shots, giving 72 gauge records. The following are the results of the analysis:

For grade No. 1:

$$K = 33.00 \pm 0.91$$

$$P = \sqrt[3]{\left(\frac{6636\,(\mathcal{S}+67)\,C}{(D+0.01)^{2.1}}\right)^2} \qquad (34c)$$

For grade No. 2:

$$K = 27.83 \pm 0.72$$

$$P = \sqrt[3]{\left(\frac{6636\,(\mathcal{S}+43)\,C}{(D+0.01)^{2.1}}\right)^2} \qquad (34d)$$

The following table exhibits the data, and a comparison between the measurements and formulæ:

Summary of experiments with electric powder No. 1.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
616	1	33	4	1.62	5,745	5,190	+ 555	
617	1	33	4	1.62	5,853		+ 663	
618	1	33	4	1.62	5,955		+ 765	
631	2	33	4	1.62	7,505	8,230	− 725	
632	2	33	4	1.62	8,008		− 222	
633	2	33	4	1.62	6,681		− 1,549	

Summary of experiments with electric powder No. 1—Continued.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet*	*Pounds.*	*Pounds.*	*Pounds.*	
634	3	33	4	1.62	11,015	10,780	+ 235	
635	3	33	4	1.62	11,298		+ 518	
636	3	33	4	1.62	11,408		+ 628	
637	4	33	4	1.62	12,368	13,070	− 702	
638	4	33	4	1.62	7,850		....	Charge wet.
639	4	33	4	1.62	12,080		− 990	
640	5	33	4	1.62	14,927	15,160	− 233	
641	5	33	4	1.62	13,781		− 1,379	
Arithmetical means					9,740	9,927	705	

Summary of experiments with electric powder No. 2.

619	2	33	4	1.62	8,189	7,370	+ 819	
620	2	33	4	1.62	6,636		− 734	
621	2	33	4	1.62	6,248		− 1,122	
622	3	33	4	1.62	10,997	9,660	+ 1,337	
623	3	33	4	1.62	10,646		+ 986	
624	3	33	4	1.62	9,708		+ 48	
625	4	33	4	1.62	11,097	11,700	− 603	
626	4	33	4	1.62	336		− 364	
627	4	33	4	1.62	,074		− 626	
628	5	33	4	1.62	13,718	13,580	+ 138	
629	5	33	4	1.62	13,235		− 345	
630	5	33	4	1.62	13,442		− 138	
Arithmetical means					10,527	10,577	605	

Designolle Powder.—Picric acid is said to have been discovered in 1788 by Haussman, while treating indigo with concentrated nitric acid. Within a few years chemists have derived it from other substances, especially from carbolic acid. It is a crystalline body, of a brilliant golden yellow, bitter to the taste, and largely used as a dye. When heated to 600° Fahr. it decrepitates with violence.

The salts obtained by treating many of the bases with picric acid possess detonating properties. The one best known is potassium picrate, which forms golden crystals, having a metallic reflection. Insoluble in alcohol, and but slightly soluble in water, it detonates violently at 600° Fahr. Its action is akin to that of the fulminates in suddenness; and to regulate this property, Designolle has mixed it with potassium nitrate and charcoal, thus forming an explosive vastly more powerful than gunpowder. To obtain the maximum explosive energy he employs equal parts of potassium nitrate and potassium picrate. For use in rifles, from 12 to 20 per cent. of potassium picrate is used, with a small amount of charcoal. For cannon, only from

8 to 12 per cent. of potassium picrate is employed. Under the name of *poudre Designolle* this compound has been considerably manufactured in France for military purposes, both for large guns and for torpedoes. It is dangerous to handle, by reason of its sensitiveness to friction; and a serious accident in Paris, resulting from this fault, caused it to be discarded.

The sample used in my experiments was made to order by Mr. C. H. Kraft, of Brooklyn. It consisted of equal parts of potassium picrate and potassium nitrate, in fine powder mechanically mixed.

Twelve shots were fired in the 4-foot ring, giving 72 gauge records; none of which, when subjected to the usual analysis, were rejected by Peirce's Criterion. The results were the following:

$$K = 32.50 \pm 0.58$$

$$(34e) \qquad P = \sqrt[3]{\left(\frac{6636\,(S + 65)\,C}{(D + 0.01)^{2.1}}\right)^2}$$

The following table exhibits the data, and a comparison between the measurements and the formula:

Summary of experiments with Designolle powder.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
651	2	33	4	1.62	8,795	8,160	+ 635	
652	2	33	4	1.62	8,323		+ 163	
653	2	33	4	1.62	8,481		+ 321	
654	3	33	4	1.62	11,069	10,710	+ 359	
655	3	33	4	1.62	11,170		+ 460	
656	3	33	4	1.62	10,643		− 67	
657	4	33	4	1.62	11,756	12,950	− 1,194	
658	4	33	4	1.62	11,716		− 1,234	
659	4	33	4	1.62	11,894		− 1,056	
660	5	33	4	1.62	15,848	15,030	+ 818	
661	5	33	4	1.62	14,507		− 523	
662	5	33	4	1.62	14,559		− 471	
Arithmetical means					11,564	11,713	608	

Brugere, or Picric Powder.—This explosive, unlike the preceding, is not liable to accidental explosion from rough handling. Its base is ammonium picrate, which differs from the potassium salt in many of its properties; thus, when ignited by a flame it burns gradually without explosion, and it is not sensitive to friction. Brugere powder has little tendency to absorb moisture from damp air, and is much more violent than gunpowder. For these reasons it has been used in shells with good results in England, and has been experimented with at Newport as an explosive for offensive torpedoes.

The powder used in my experiments was made to order by Mr. C. H. Kraft, of Brooklyn. It consisted of equal parts of ammonium picrate and potassium nitrate, in fine powder, intimately mixed, but not granulated. The latter process is quite safe, and should not be neglected when large quantities are to be used; but for the small charges and powerfully detonating fuzes employed in these experiments, it is probable that no loss resulted from this mechanical condition of the powder.

Twelve shots, giving 72 gauge records, were fired in the 4-foot ring, and Peirce's Criterion rejected none of them. The usual analysis gave the following results:

$$K = 41.92 \pm 0.94$$

$$(34f) \qquad P = \sqrt[3]{\left(\frac{6636\,(S + 110)\,C}{(D + 0.01)^{2.1}}\right)^2}$$

The following table exhibits the data, with a comparison between the measurements and the indications of the formula:

Summary of experiments with Brugere, or picric powder.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
642	2	33	4	1.62	10,787	9,670	+ 1,067	
643	2	33	4	1.62	10,821		+ 1,151	
644	2	33	4	1.62	10,027		+ 357	
645	3	33	4	1.62	12,896	12,670	+ 226	
646	3	33	4	1.62	13,003		+ 333	
647	3	33	4	1.62	13,426		+ 756	
648	4	33	4	1.62	14,592	15,360	− 768	
649	4	33	4	1.62	14,610		− 750	
650	4	33	4	1.62	14,065		− 1,295	
663	5	33	4	1.62	16,231	17,820	− 1,589	
664	5	33	4	1.62	16,994		− 826	
665	5	33	4	1.62	16,055		− 1,765	
Arithmetical means					13,621	13,880	907	

In Appendix A three shots (Nos. 480, 481, and 482) are reported as fired with three grades of picric powder, in 1877. The precise composition was accidentally lost, and hence they are not discussed here. They all contained charcoal, and were comparatively weak.

Explosive Gelatine.—This, the latest explosive compound* devised by Nobel, has not yet made its appearance in our market. Various efforts were made, immediately after its announcement in Europe, to import a sample for trial; but the shipment across the ocean could not be arranged. Facilities for manufacturing the material in bulk are lacking at Willets Point, and it therefore had received no experimental study when this report was officially transmitted to the Board of Engineers in December, 1880. Since that date a sample (about 100 pounds) made by Professor Hill, of the Naval Torpedo Station at Newport, has been kindly presented to us by Captain Ramsey, and to his courtesy I am thus indebted for the opportunity of making the following

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* The following statement respecting this explosive is from Vol. IV, No. 12, Occasional Papers of the Royal Engineer Institute, being extracts from the "Revue d'Artillerie" for 1879, translated by Capt. H. Jekyll, R. E.:

"Explosive gelatine is a peculiar description of gun-cotton, entirely soluble in nitro-glycerine, and forming with it a gelatinous or gummy substance more powerful than nitro-glycerine, scarcely affected by water, and giving out no trace of nitro-glycerine under the strongest pressure.

"It can be rendered insensible to mechanical action, while retaining its power, by mixing it with certain substances soluble in nitro-glycerine, such as benzine, etc.

"It is composed of 93 parts of nitro-glycerine and 7 of soluble gun-cotton.

"The experiments demonstrated its insensibility to shock, to friction, and to the pressure or action of water, and further, that to produce complete explosion in a free state, and to develop the great force corresponding to its chemical composition, it would be necessary to use, even in its soft state, a peculiarly powerful detonator.

"One gramme of fulminate of mercury was insufficient to detonate a charge in a soft state contained loosely in a tin case. Fragments of gelatine as large as a pin's head, or even as a small pea, were found scattered about after the explosion.

"Under the blow of a pile engine the gelatine was insensible to a blow of 3.5 kilogrammetres, while dynamite instantly explodes under 1 kilogrammetre.

"The gelatine is unaffected by submersion in water, even at a temperature of 158° Fahr., and showed no trace of exudation after eight days at a temperature of 113° Fahr.

"From these properties it would appear very superior to dynamite for military purposes, provided a sufficiently powerful primer can be made to insure complete detonation.

"A new explosive, suitable to all requirements, has been prepared from this substance, and may be termed *gelatine explosive de guerre*. It is produced by adding to the gelatine a small proportion of camphor, a substance highly soluble in nitro-glycerine.

"A very small proportion of camphor renders the explosive insensible to blows, even of projectiles at short range; it also enables it to resist the action of water, and imparts to it an explosive force far superior to dynamite or compressed gun-cotton.

"For complete detonation a special primer is needed of extra power, composed of a mixture of nitro-glycerine with a description of nitro-cellulose prepared in a particular manner.

"The composition of *gelatine explosive de guerre* is—

"Camphor	4
"Explosive gelatine	96
	100

"Explosive gelatine consisting of—

"Nitro-glycerine	90
"Soluble gun-cotton	10
	100

"In appearance it is gelatinous, elastic, transparent, and pale yellow in color.

"Its density is 1.6; it can be cut with a knife, and under the severest pressure it shows no trace of nitro-glycerine. At temperature of 122° Fahr. to 140° Fahr. it softens a little, but seldom becomes greasy.

"When inflamed in the open air it burns like dynamite or dry compressed gun-cotton.

"Two hundred grammes were placed in a tin cylinder 6 inches long. When ignited with a slow match penetrating the middle of the charge it burned quietly with a long, yellow flame, though the case was closed with a metal cover. When half the charge was burnt the cover was simply raised by the pressure without any explosion taking place.

"A composition of 10 parts of camphor and 90 of explosive gelatine may be exposed for a week to a temperature of 158° Fahr. without showing any signs of decomposition; 4.4708 grammes of the same composition in a watch glass were exposed for seven hours a day during two months to a temperature of from 104° to 122° Fahr. No decomposition took place, merely a partial volatization of camphor and nitro-glycerine.

"After the experiment the specimen still weighed 4.1239 grammes, so that the loss of weight amounted to only .3469 gramme, or 7.7 per cent. As nitro-glycerine becomes volatile at 104°, part of the loss is accounted for, so that half the camphor in the composition can scarcely have evaporated, though the circumstances were exceptionally favorable to evaporation.

"Experiments are needed to determine the rapidity of evaporation of the camphor and the effect of its volatization on the properties of the composition.

"The preservative action of camphor, especially at exploding temperatures, is extremely notable. Thus pure explosive gelatine, slowly heated, detonates at 400° Fahr., or rapidly at 464°. If 10 per cent. of camphor are added it will not detonate at all when slowly heated, but becomes diffused in sparks. When heated rapidly it explodes at a temsupplementary experiments, in time for insertion before the book has passed through the press. Both the Atlantic and Pacific Giant Powder Companies are now taking steps to manufacture explosive gelatine for our market, and hereafter there will probably be no difficulty in continuing and extending the trials needful to determine whether or not it should supersede dynamite No. 1 in our Torpedo Service.

The sample prepared by Professor Hill consisted of 89 per cent. of nitro-glycerine, 7 per cent. of collodion gun-cotton, and 4 per cent. of camphor. It was forwarded in slabs wrapped in oiled paper, each weighing about 10 pounds. Being received in mid-winter, it remained frozen in the magazine until April 18, 1881—a whitish opaque solid of about the consistency of cheese. Small pieces in this state, lashed to a service low-tension fuze primed with 24 grains of fulminate of mercury, failed to explode; and the same result followed when three of the fuzes were fired simultaneously in contact.

In April the slabs were moved to a wooden shed with the papers unwrapped, and under the influence of the spring weather they soon began to thaw, changing in appearance into a thick semi-transparent jelly of a pale yellow color. The substance in this condition possessed considerable toughness, but could be easily cut with a knife and rolled in strips. Its specific gravity was about 1.6, or nearly that of dynamite No. 1 compacted in cartridges. A couple of ounces laid on a zinc plate and exposed for about six hours to a hot sun, when the thermometer in the shade indicated 90° Fahr., softened sufficiently to flatten by gravity, but no oil exuded, and when ignited by a match the mass burned like gun-cotton, with a strong, hissing flame. A small piece plastered upon the copper cap of a service fuze exploded with a loud report, indicating an increase in sensitiveness.

In only one instance (May 10, 1881) was any important exudation of nitro-glycerine noted, when about half a dozen drops appeared by the side of one of the

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perature too high for measurement by ordinary apparatus. Mixed with 10 per cent., or even 4 per cent., of camphor, this substance will not explode at the same temperature as gunpowder, viz, 570° to 600° Fahr., but simply burns, producing sparks.

"It may be inferred from the above that its liability to explosion from a blow would be equally slight, especially having regard to the elastic, gelatinous consistency of the material.

"It requires a peculiarly powerful fuze to insure the certainty of detonation. The inertness of the composition increases rapidly with the proportion of camphor. With the addition of only 4 per cent. detonation cannot be insured with 2 grammes of fulminate of mercury, a primer of compressed gun-cotton, or a mixture of 75 parts of nitro-glycerine with 25 of gun-cotton, as used in the Austrian service.

"A special primer is therefore required. It is composed of 60 per cent. of nitro-glycerine and 40 per cent. of a nitrous substance obtained from cellulose by a peculiar process.

"Owing to the composition of cotton, it is impossible to obtain from it tri-nitro-cellulose. In Abel's process much of the cotton is only partially nitrogenized, and some not at all, while Lenk's method is still less efficient.

"If sulphuric acid be made to act upon cotton a white powder is obtained, named hydro-cellulose. This substance is extremely susceptible to the action of nitric acid. The result is, as regards explosive force, a highly nitrogenized description of cellulose.

"This new gun-cotton appears in the form of a fine powder resembling flour, but exhibits under the microscope the specific structure of cotton. It is not a great absorbent of nitro-glycerine, like Abel's or Lenk's cotton, which are divided by mechanical means, neither does it share their property of becoming gelatinous with this liquid.

"The mixture of 60 per cent. of nitro-glycerine with 40 per cent. of nitro-hydro-cellulose yields a soft, white, soapy, and entirely homogeneous substance. Twenty grammes can be placed in an Austrian cartridge, which will hold but 15 to 17 of the regulation composition, and thus furnishes a primer capable of exploding *gelatine explosive de guerre*, and surpassing in detonating power all known exploding agents."

thawing slabs; but the surface of the mass in this condition was usually oily, and by absorbing with paper and striking with a hammer a sharp explosion could be obtained, proving the presence of free nitro-glycerine. Handling the jelly always produced the customary nitro-glycerine headache.

The following experiments were made upon the gelatine, when unfrozen, to test the effect of violent concussions. A slice half an inch in thickness was suspended in paper and pierced by a bullet from the regulation Springfield rifle fired at 25 yards; result, nil. This experiment was repeated, without explosion, when the gelatine was backed by an inch board. The range was then increased to 45 yards, and the bullet was driven with a like result through the explosive and flattened on an half-inch iron plate against which it was resting. Finally, a 10-pound slab was lashed to a vertical board one inch thick, and was pierced by a service bullet at a range of 100 yards. The ball thus traversed about 3 inches of the gelatine without effect. In all these trials the explosive was in its semi-transparent, jelly-like condition.

To test its tendency to sympathetic explosion a few experiments were carried out in the manner soon to be described for dynamite. Half-pound cartridges wrapped in paper were submerged 5 feet below the water surface at distances of 15, 10, 5, and 3 feet from a fuze can containing one pound of dynamite No. 1. Detonating the latter produced no effect upon the explosive gelatine. Under like conditions dynamite No. 1 explodes up to a range of 20 feet.

These experiments, confirmatory of those reported abroad, show that the new explosive possesses much less liability to accidental detonation than dynamite No. 1, an advantage which in military operations on land can hardly be overestimated.

This explosive gelatine proved to be wholly soluble in ether, and in a mixture of ether and alcohol, but in alcohol alone it dissolved with difficulty. Unlike its operation with other nitro-glycerine compounds, this process did not separate the oil from the base. By evaporation, or by the addition of water, a white mass was precipitated which resembled thick flour paste in appearance. When subjected to moderate heat a tendency to very gradually resume the semi-transparent appearance was developed.

Water produced no exudation of nitro-glycerine, another important advantage over dynamite No. 1, from which, as already stated, it abstracts the nitro-glycerine to a greater or less extent, dependent upon the compactness of the material. After several hours' submergence, however, the color changed to the opaque white characteristic of the precipitation from ether.

The new explosive was next tested for intensity of action, in the usual manner, in the 4-foot ring. All authorities agree that this substance is more difficult to detonate than dynamite, but a few trials on land indicated, when the gelatine is in a soft state, that a violent explosion could be caused by the service fuze charged with 24 grains of fulminating mercury contained in a copper cap. To determine the "order" of this explosion sixteen shots were fired in the ring, of which two failed and the rest exploded. The results are given in detail in the following table and in Appendix A. The figures establish some interesting facts, which will soon receive further notice.

To obtain a measure of the normal intensity of action of the explosive when certainly detonated, sixteen shots were fired with priming charges consisting of 3 ounces of dry compressed gun-cotton, or 3 ounces of dynamite No. 1 in a loose state, each fired by a low-tension fuze charged with 20 grains of fulminating mercury. The details of these experiments are given in the following table and in Appendix A.

Two of the shots (Nos. 690 and 691) were designed to test the effect of freezing the gelatine. The charges (3 pounds) were placed in a soft state round the primings (one of gun-cotton and the other of loose dynamite No. 1) in No. 1 tin cans, which were then packed in ice for seventy-nine hours. The explosive assumed the appearance of a white solid, so hard that it could not be indented by a stick; but, as appears from the table, no effect was produced upon the normal intensity of action due to perfect detonation.

Summary of explosive gelatine experiments.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
666	1	33	4	1.62	8,624	8,832	— 208	One fuze; 20 grains fulminating mercury.
667	1	33	4	1.62	8,480		— 352	Do.
668	1	33	4	1.62	8,962		+ 130	Do.
669	2	33	4	1.62	11,047		....	Do.
670	2	33	4	1.62	9,847		....	Do.
671	2	33	4	1.62	8,406		....	Do.
672	3	33	4	1.62	8,752		....	Do.
673	3	33	4	1.62	13,468		....	Do.
674	3	33	4	1.62	12,036		....	Do.
678	3	33	4	1.62	9,560		....	Two fuzes; 40 grains fulminating mercury.
675	4	33	4	1.62	20,967		....	One fuze; 20 grains fulminating mercury.
676	4	33	4	1.62	16,462		....	Do.
677	5	33	4	1.62	15,770		....	Do.
679	5	33	4	1.62	11,823		....	Do.
680	5	33	4	1.62	6,402		....	Do.
681	5	33	4	1.62	10,457		....	Do.
682	2	33	4	1.62	15,894	14,020	+ 1,874	Primer, 3 ounces of gun-cotton. Rejected by Peirce's Criterion.
684	2	33	4	1.62	9,360		....	Primer, 3 ounces of dynamite. This charge had failed with a fuze.
683	3	33	4	1.62	19,893	18,370	+ 1,523	Primer, 3 ounces of gun-cotton.
685	3	33	4	1.62	13,567		....	Primer, 3 ounces of dynamite. This charge had failed with a fuze.
693	3	33	4	1.62	14,024		— 4,346	Primer, 3 ounces of dynamite. Rejected by Peirce's Criterion.
694	3	33	4	1.62	15,125		— 3,245	Primer, 3 ounces of dynamite.
690	3	33	4	1.62	17,157		— 1,213	Primer, 3 ounces of gun-cotton, *frozen*.
691	3	33	4	1.62	18,601		+ 231	Primer, 3 ounces of dynamite, *frozen*.
692	3	33	4	1.62	18,802		+ 432	Do.
695	3	33	4	1.62	18,114		— 256	Primer, 3 ounces of gun-cotton.
696	3	33	4	1.62	17,808		— 562	Do.
697	3	33	4	1.62	18,262		— 108	Do.

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Summary of explosive gelatine experiments—Continued.

No. of shot.	Charge.		Ring.	Distance to gauges. (D)	Pressure per square inch. (P) Mean of six gauges.			Remarks.
	Weight. (C)	Submergence. (S)			Observed.	Computed.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
686	4	33	4	1.62	22,776	22,250	+ 526	Primer, 3 ounces of dynamite.
687	4	33	4	1.62	22,693		+ 443	Primer, 3 ounces of gun-cotton.
688	5	33	4	1.62	23,982	25,850	− 1,868	Do.
689	5	33	4	1.62	24,954		− 896	Primer, 3 ounces of dynamite.
Arithmetical means					17,303	17,767	1,071	

The foregoing table exhibits a summary of the results of these ring trials, thirty-four in number (including the two failures). The charges of the latter, each consisting of 4 pounds primed with a single fuze containing 20 grains of fulminating mercury in a copper cap, were recovered, although the explosion of the fuzes burst open the cans, and the same material was again used in shots No. 684 and No 685. Although then primed with 3 ounces of loose dynamite, the intensity developed was anomalously small, suggesting that possibly an excess of camphor might have been present in the single slab from which they were both taken.

A scrutiny of these data established the fact that, except with the 1-pound charges, the explosions obtained with a single fuze (and with two fuzes as well in shot No. 678) were uniformly *of an order below detonation*, and they were accordingly omitted in the analysis. For the reason given above, shots No. 684 and No. 685 were also thrown out as anomalous. This left seventeen shots, or one hundred and two gauge records, from which to derive the normal equation of the explosive when perfectly detonated.

The first step in framing this equation is to correct the indicated mean pressures for the effect of the 3-ounce primers. This was done by computing, with the gun-cotton and dynamite formulæ, the mean pressure which would have been registered upon the gauge pins by charges of $2\frac{3}{16}$, $3\frac{3}{16}$ pounds, etc., of these explosives, and then determining in each case the proportional part due to 3 ounces. These amounts are the following, which, in preparing the foregoing summary, have been subtracted from the mean pressures actually measured and reported in Appendix A. The table, therefore, gives the intensity of action due to the *explosive gelatine alone* without the primers.

Deduct for 2-pound charges; for dynamite primer, 1,092 pounds; for gun-cotton primer, 952 pounds.
Deduct for 3-pound charges: for dynamite primer, 963 pounds; for gun-cotton primer, 840 pounds.
Deduct for 4-pound charges; for dynamite primer, 879 pounds; for gun-cotton primer, 767 pounds.
Deduct for 5-pound charges; for dynamite primer, 818 pounds; for gun-cotton primer, 714 pounds.

The seventeen shots thus corrected, when subjected to the usual analysis, are reduced to fifteen in number, Nos. 682 and 693 being rejected by Peirce's Criterion, giving:

$$K = 73.2 \pm 1.14$$

$$P = \sqrt[3]{\left(\frac{6636\,(\vartheta + 259)\,C}{(D + 0.01)^{2.1}}\right)^2} \qquad (34f)$$

The mean pressures in the seventh column of the foregoing table have been computed by this formula, and the accordances are regarded as sufficiently close to warrant its provisional adoption when the charge is *perfectly detonated.* It indicates the relative intensity of action of explosive gelatine as compared with dynamite No. 1 to be 1.17 in a horizontal plane, 1.13 vertically over the charge, and 1.25 vertically under the charge. These figures show that for use in sub-aqueous explosions the new explosive is the strongest known to modern science.

The possession of this formula renders it easy to analyze the partial explosions caused by 20 grains of fulminating mercury in a copper cap, and reported in the foregoing table.

To do this in the simplest manner, it is only needful to compare the registered mean pressures with the corresponding computed values. Should these ratios prove to be constant in the different experiments, the usual assumption of a definite "second order" of explosion would receive confirmation. Thus:

Shot No. 666, charge 1 pound; full detonation.
Shot No. 667, charge 1 pound; full detonation.
Shot No. 668, charge 1 pound; full detonation.
Shot No. 669, charge 2 pounds; 0.8 detonation.
Shot No. 670, charge 2 pounds; 0.7 detonation.
Shot No. 671, charge 2 pounds; 0.6 detonation.
Shot No. 672, charge 3 pounds; 0.5 detonation.
Shot No. 673, charge 3 pounds; 0.7 detonation.
Shot No. 674, charge 3 pounds; 0.7 detonation.
Shot No. 678, charge 3 pounds; 0.4 detonation.
Shot No. 675, charge 4 pounds; 0.9 detonation.
Shot No. 676, charge 4 pounds; 0.7 detonation.
Shot No. —, charge 4 pounds; did not explode.
Shot No. —, charge 4 pounds; did not explode.
Shot No. 677, charge 5 pounds; 0.6 detonation.
Shot No. 679, charge 5 pounds; 0.5 detonation.
Shot No. 680, charge 5 pounds; 0.2 detonation.
Shot No. 681, charge 5 pounds; 0.4 detonation.

These results are confirmatory of the opinion announced on page 63, that when detonation fails there may be *not one alone but several orders* of inferior explosions, differing in intensity, and probably characterized by different chemical reactions. They also suggest that as the size of a charge imperfectly fired is increased its order is degraded—a very important point in practice, if verified by further experiment.

As to the question of the relative merit of gun-cotton and uncompressed dynamite as a primer for detonating explosive gelatine, these trials are not decisive. In general the two substances appear to be equally effective, but an occasional tendency to partial failure with dynamite suggests that perhaps the size of the primer with that explosive should be increased. Indeed, a mixture of uncompressed dynamite No. 1 with explosive gelatine might be a useful combination for buoyant mines, where the charge is liable to be thrown about by the concussion of the vessel.

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For ground mines the greater density of the explosive gelatine would permit the charge to be increased in the ratio of about 5 to 3 for a given space in the torpedo, giving a total increase of nearly 90 per cent. in the intensity of action exerted upon a vessel over the mine.

In fine these trials reopen the question of the best explosive for our submarine mining service. It would be premature to base a decided opinion on so important a matter upon these few experiments; but it is evident that the new explosive is worthy of elaborate investigation.

Mixed Explosives.—In rock blasting better results are sometimes claimed to be obtained from a mechanical mixture of two different explosives than from either of them separately. A few shots were fired in the 4-foot ring to determine whether any such advantage can be detected under water.

The first charge (shot No. 182) was composed of 4 pounds of dualin and 1 pound of dynamite, fired in a tin can submerged 35 feet, in water 108 feet deep.

The proper method of computing the normal effect of this combination is to find by the dualin formula (equation 28) the value of P for a 5-pound charge; then to find the same by the dynamite formula (equation 21); then to add four-fifths of the first value to one-fifth of the second. This process gives:

Dualin effect	= $\frac{4}{5}$ (24,480) =	19,584
Dynamite effect	= $\frac{1}{5}$ (22,090) =	4,418
Computed (P)		24,002
Observed (P) (mean of 6 gauges)		23,318
Difference		684

The next tests were made with equal parts, by weight, of dynamite No 1 and vulcan powder No. 1 (shots 461, 462, and 463). The total charge was 3 pounds, contained in a can No. 1; submergence, 35 feet; depth of water, 50 feet. The three observed mean pressures were 13,522, 14,379, and 13,285 pounds, respectively, each a mean of six gauges. The above computation gives:

Dynamite effect	= $\frac{1}{2}$ (15,710) =	7,855
Vulcan powder effect	= $\frac{1}{2}$ (12,020) =	6,010
Computed (P)		13,865
Observed (P) (mean of 18 gauges)		13,729
Difference		136

Since computation based on the normal action of the explosives so correctly predicts the results of these trials, it may legitimately be inferred that no increased intensity of action was developed by the mixture.

Discussion of the Formulæ.—The foregoing analysis has demonstrated that the available energy of the several explosive compounds when fired under water, and their intensity of action upon bodies subjected to their influence, may each be expressed by one and the same general formula, when the proper value for the individual explosive is assigned to a single quantity (E). These general formulæ are:

$$W = \frac{0.21\,(\vartheta + E)\,C}{(D + 0.01)^{2.1}} \tag{35}$$

$$P = \sqrt[3]{\left(\frac{6636\,(\vartheta + E)\,C}{(D + 0.01)^{2.1}}\right)^2} \tag{36}$$

Several points worthy of attention are suggested by these formulæ.

(1.) The most obvious deduction from the analysis has already been pointed out, viz, that the available energy of the explosive is directly proportional to the charge, and inversely proportional to the square of the distance (nearly); while the intensity of action, deduced from work actually performed, is proportional to the two-thirds power of the charge and, inversely, to the 1.4 power of the distance. In other words, the element of time cannot be ignored in passing from kinetic energy to actual mechanical work like the destruction of a vessel.

(2.) The absence in the formulæ of any practically important function of the submergence of the charge, indicates that a floating mine is deep enough for the requirements of the torpedo service provided it be planted below the level of the side plating of armored ships of war.

(3.) The great effect upon the numerical value of P produced by varying the direction of the line of action in vertical planes passing through the charge and vessel, emphasizes the importance of placing the former under the latter when possible.

(4.) The small exponent of C (only $\frac{2}{3}$) in the value of P shows that with a given weight of the explosive many moderate charges block a channel more effectually than a few large ones. Thus a mine containing 500 pounds is only 2.9 times as effective as one of 100 pounds.

(5.) These formulæ afford the means of determining the relative merit of different explosives with great precision, since each represents the generalized result of many trials under varying conditions. Thus denoting by P′ and E′, and P″ and E″, the numerical values of these quantities for two given explosives, we have:

$$P' : P'' :: \sqrt[3]{\left(\frac{6636\,(\vartheta + E')\,C}{(D + 0.01)^{2.1}}\right)^2} : \sqrt[3]{\left(\frac{6636\,(\vartheta + E'')\,C}{(D + 0.01)^{2.1}}\right)^2}$$

Hence:

$$P' = P''\sqrt[3]{\left(\frac{\vartheta + E'}{\vartheta + E''}\right)^2}$$

This expression implies, what is well known to be true, that the greater the resistance to be overcome the more distinctly marked are the differences between the intensity of action of the several explosive agents. In other words, the most severe test of their relative power under water is their action vertically downward. As the work required of them in submarine mining, however, varies from the horizontal plane upward, their relative horizontal action appears to be the true criterion.

Relative strength of explosive compounds fired under water.

Explosive.	Percentage of nitro-glycerine.	Value of E.	Relative intensity of action. Downward. $\vartheta = 0$.	Relative intensity of action. Horizontally. $\vartheta = 90°$.	Relative intensity of action. Upward. $\vartheta = 180°$.	Remarks.
Dynamite No. 1	75	186	100	**100**	100	Standard of comparison.
Gun-cotton	..	135	81	**87**	91	
Dualin	(?)	232	116	**111**	108	
Rendrock	20	101	67	**78**	84	
Do	40	160	91	**94**	95	
Do	60	166	93	**95**	96	
Dynamite No. 2	36	120	75	**83**	88	
Vulcan powder No. 1	30	99	66	**78**	83	
Vulcan powder No. 2	35	114	72	**82**	86	
Mica powder No. 1	52	119	74	**83**	87	
Mica powder No. 2	40	46	39	**62**	73	
Nitro-glycerine	100	111	71	**81**	86	
Hercules No. 1	77	211	109	**106**	105	
Hercules No. 2	42	118	74	**83**	87	
Electric No. 1	33	67	51	**69**	77	
Electric No. 2	28	43	38	**62**	72	
Designolle	0	65	50	**68**	77	
Brugere	0	110	71	**81**	86	
Explosive gelatine	89	250	125	**117**	113	

This table is fruitful in valuable and interesting suggestions. For example, a comparison of pure nitro-glycerine with dynamite No. 1 reveals what, at first sight, appears to be a paradox. One pound of pure nitro-glycerine has only 81 per cent. of the intensity of action of three-fourths of a pound absorbed by an inert substance, which can add nothing to the heat or gases developed! This fact, which was discovered early in these trials (in 1871), was considered to be so extraordinary as to require careful verification and study.

Among the explanations which suggested themselves, was a possible variation in the strength of nitro-glycerine itself, depending upon a difference in the chemical composition of different samples. As already seen, this was tested practically; and so far as the experiments went, was found to be without foundation. Still, as the evidence was only negative, it was deemed better to put the matter beyond any doubt by testing, under identical conditions, nitro-glycerine and dynamite No. 1 made therefrom. The officers of the Atlantic Giant Powder Company kindly gave their assistance in the matter, by bringing to Willets Point some of their prepared kieselguhr imported from Europe, and making the dynamite from nitro-glycerine supplied by me. I personally weighed the ingredients in the normal proportions, and immediately fired equal charges of the two explosives, in the 4-foot ring submerged 35 feet under the surface, in water 100 feet deep. The following table exhibits the results:

Comparison of nitro-glycerine and dynamite made therefrom.

Nitro-glycerine made by Chester.				Dynamite No. 1, from same nitro-glycerine.			
No. of shot.	Charge.	Distance to gauges.	Mean pressure. (6 gauges.)	No. of shot.	Charge.	Distance to gauges.	Mean pressure. (6 gauges.)
	Pounds.	*Feet.*	*Pounds.*		*Pounds.*	*Feet.*	*Pounds.*
206	1	1.62	7,244	209	1	1.62	7,168
204	2	1.62	10,197 }	211	2	1.62	14,265
207	2	1.62	9,155 }				
205	3	1.62	13,548	213	3	1.62	17,366
215	4	1.62	14,785	214	4	1.62	18,487
208	5	1.62	22,263	216	5	1.62	23,168
Mean			13,503	Mean			16,091

Adopting the mean of the five shots with each explosive as the true index of its intensity, we have for the relative strength of liquid nitro-glycerine as compared with dynamite No. 1 in sub-aqueous explosions, weight for weight: $\frac{13503}{16091} = 0.85$. The above tabular expression gives for this ratio 0 81. There can, therefore, remain no doubt that variations in the quality of the nitro-glycerine have nothing to do with the extraordinary fact under discussion; and hence, that the explanation must be sought in the physical conditions of the problem.

Dynamite No. 1 is simply nitro-glycerine granulated. With gunpowder, granulation promotes intensity of action by opening passages for the initial flame to penetrate the mass, and thus accelerate the formation of the gases. Were this the true explanation of the phenomenon in question, a similar relative strength between the two explosives would also be shown in rock blasting—which is contrary to observation, as nitro-glycerine in hard rock is admitted to be by far the stronger of the two.

Let us suppose, on the other hand, that granulating nitro-glycerine by absorbing it in kieselguhr has precisely the contrary effect; *i. e.*, that the particles of silica slightly retard chemical action—as is not unlikely, since in detonation the reactions may occur within the molecules. This idea appears to me to supply the required explanation; for the resistance opposed by water being of a slightly yielding character, may exact more time than is afforded by nitro-glycerine pure and simple. I regard this as the most plausible explanation of a fact which, although novel, is so well established by my experiments, that its correctness can hardly be questioned.

Referring now to the two grades of mica powder, it will be noticed that, as compared with each other, the intensities developed are normal; *i. e*, they are directly proportional to the charge of nitro-glycerine. The explosive, however, is vastly inferior in intensity to dynamite No. 1; indeed the No. 2 grade stands at the foot of the list. The reasons advanced by Mr. Mowbray for believing this powder to be quicker even than nitro-glycerine itself, have already been given; and, since we have just seen that the latter is too quick for advantageous use in sub-aqueous explosions, this result is precisely what is to be expected from his theory. The powder is so quick as to be unsuited for sub-aqueous work.

Dynamite No. 2 and vulcan powder differ but slightly in the composition of the absorbent; and their relative intensity proves to be measured by the proportion of nitro-glycerine which they contain, at least up to 36 per cent.

With rendrock, the gain resulting from increasing the proportion of nitro-glycerine from 20 to 40 per cent. is 16 per cent.; but above that limit the advantage is slight. In other words, the absorbent adds so much to the forces developed by the explosion, that 40 per cent. of nitro-glycerine is as much as can economically be used in sub-aqueous explosions.

Rendrock as supplied to the trade (40 per cent. of nitro-glycerine), is evidently better adapted for use in explosions under water than any of the other nitro-glycerine compositions based upon gunpowder as the absorbent—of which dynamite No. 2 is the original type.

The two grades of hercules powder are similar in strength to those of dynamite; but as No. 1 contains a charge of nitro-glycerine too large for the absorbing power of its base, more trouble from wetting and freezing is to be apprehended, and more danger from high temperature. For these reasons it is regarded as decidedly inferior for the torpedo service.

The strength of the two grades of electric powder is nearly proportional to their charges of nitro-glycerine; but the base apparently adds less to the effective power of the explosive than is the case with several of its competitors.

Both of the picrate powders are much inferior in strength to dynamite No. 1; but as Brugere powder, the stronger of the two for use under water, is quite safe to handle, it should decidedly have the preference over Designolle powder. Indeed, for sub-aqueous explosions, the former is not much inferior to gun-cotton, and being quite unaffected by frost it may prove useful for certain special purposes in submarine mining.

Leaving the strongest of them all, explosive gelatine, out of consideration as not yet sufficiently studied, this tabular comparison of the several explosives indicates that dualin, as supplied for these tests, ranks first in intensity of action; hercules powder No. 1 ranks second; and dynamite No. 1 ranks third This classification refers only to explosions under water.

In selecting the best explosive for the torpedo service, normal intensity of action is only one of many points to be considered. Some of the others admit of investigation by experiment, and the results of such trials will now receive attention.

Effect of Wetting the Charge.—This matter is of great importance in submarine mining; not only because leaks are always possible, but also because the aqueous vapor of the air enclosed in the torpedo is condensed by submergence in cold water, and thus supplies more moisture than is usually imagined. The inside of a metallic case which has been planted in warm weather, is always wet to the touch, and sometimes considerable water is thus collected.

Nitro-glycerine is absolutely unaffected by water—indeed, is usually tamped with it when practicable.

The effect of wetting gun-cotton was discussed when deducing the formula for that explosive; and moisture was shown to exert no marked influence upon the intensity of action developed.

To test the matter for dualin, the following experiments were made in May, 1872:

Two shots (Nos. 181 and 182) were fired in the 4-foot ring, submerged 35 feet in water 108 feet deep. The charges for each of them were placed in No. 2 cans, within which were inserted hermetically closed fuze cans, containing 1 pound of dry dynamite and a detonating fuze. The empty space around the latter was filled with 4 pounds of dualin—which in shot No. 181 was thoroughly saturated with fresh water, and in shot No. 182 was dry. Result (mean of six gauge measurements):

Shot 181: (dualin, wet); observed $P = 12{,}785$.
Shot 182: (dualin, dry); observed $P = 23{,}318$.

By an analysis similar to that used in discussing mixed charges, it may be shown that in shot No. 182 the proportional parts of the observed mean pressure due to dualin and dynamite, were 19,037 and 4,281, respectively. Hence, the percentage of loss occasioned by wetting the dualin was:

$$100 - \frac{12{,}785 - 4{,}281}{19{,}037} = 55 \text{ per cent. of loss.}$$

Continuing the trials in June, 1872, shots Nos. 191 and 192 were fired under conditions identical with No. 181, except that the charge of dry dynamite was reduced to three-fourths of a pound. Result (mean of six gauges):

Shot No. 191: (dualin, wet); observed $P = 14{,}032$.
Shot No. 192: (dualin, wet); observed $P = 12{,}407$.

Applying the same analysis:

$$\text{For shot No. 191: } 100 - \frac{14{,}032 - 3{,}370}{19{,}915} = 47 \text{ per cent. of loss.}$$

$$\text{For shot No. 192: } 100 - \frac{12{,}407 - 3{,}370}{19{,}915} = 55 \text{ per cent. of loss.}$$

No further evidence was considered necessary to establish that dualin, when thoroughly wet, loses at least one-half of its normal intensity of action in sub-aqueous explosions.

It remained to determine whether dynamite No. 1 is affected in a similar manner by water.

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Four experiments were made in the 4-foot ring (Nos. 185, 186, 193, and 194) under identical conditions with those just discussed for dualin. The dry priming charge for the first two was 1 pound of dynamite No. 1, and for the last two three-fourths of a pound. The whole charge in No. 186 was dry; but it was loaded in a double case in the same manner as the others, to serve as a basis for exact comparison. Results:

Shot No. 185: (dynamite, wet); observed $P = 20,806$.
Shot No. 186: (dynamite, dry); observed $P = 22,469$.
Shot No. 193: (dynamite, wet); observed $P = 19,750$.
Shot No. 194: (dynamite, wet); observed $P = 19,809$.

Applying the same method of analysis as for dualin:

$$\text{For shot No. 185: } 100 - \frac{20,806 - 4,342}{17,369} = 5 \text{ per cent. of loss.}$$

$$\text{For shot No. 193: } 100 - \frac{19,750 - 3,370}{17,672} = 7 \text{ per cent. of loss.}$$

$$\text{For shot No. 194: } 100 - \frac{19,809 - 3,370}{17,672} = 7 \text{ per cent. of loss.}$$

These figures show that when saturated a charge of dynamite No. 1 fired under water loses only about 6 per cent. of its normal intensity of action, or but little more than appears to be the case with gun-cotton.

It will be noticed that these trials were terminated before the discovery that wet gun-cotton could be detonated was made public in England. This fact was first ascertained by Mr. Brown, chemist at the War Office, in the latter part of 1872.

In this connection it may be well to state that while a compacted cartridge of dynamite No. 1 immersed in water soon loses a large part of its nitro-glycerine by exudation, this is not true when the powder is used loose, as must always be the case in submarine mining to insure detonation when frozen. In this state nitro-glycerine remains distributed through the mass even if wetted.

It was unnecessary to extend these water tests to the other explosives; since, except for mica powder, their absorbents are all more or less soluble, and hence must totally change their composition if wetted. Mica powder, as already seen, is quite unfit for the torpedo service.

Effect of Freezing the Charge.—Frost is well known to have no effect upon dry gun-cotton; but, if wet, a mechanical disintegration of the discs is sometimes caused by the expansion of the water.

Nitro-glycerine in a liquid form is rendered almost or quite inexplosive by congelation; and, as its freezing point is much above that of water, this fact alone would be sufficient to condemn it for the torpedo service. For this reason any nitro-glycerine compound which appears suitable in other respects for submarine mining, before adoption, should be thoroughly tested as to the effect produced upon it by cold. This has been done with dualin and dynamite No. 1.

Dualin required no extended trials, for it was generally reported and believed to be peculiarly liable to accidental explosion in a frozen state, and even to become dangerous in that condition.

In January, 1872, half a dozen dualin cartridges, some loosely and some closely packed in paper, were tested with fuzes containing about 15 grains of fulminating mercury inclosed in copper caps. The samples were exposed for twenty-four hours to a temperature of 10° Fahr., but all readily detonated. Other samples exposed in paper boxes did the same without a single failure. In January, 1873, a charge of 2 pounds of dualin, thoroughly frozen, was placed in a can No. 1 and suspended 3 feet below the surface of ice, from 8 to 9 inches thick. A fuze, primed as before, caused it to explode and blow out a crater of precisely normal diameter. These facts, with other similar results, are considered conclusive as to the detonating of frozen dualin. In no single instance did a failure to explode—apparently with full effect—occur.

With dynamite No. 1 more extended investigation was needed; for the compound was generally believed to be inexplosive under the action of the ordinary fuze when frozen. The advertisement of the Giant Powder Company announced this to be the case, and common experience in practical blasting confirmed the statement. It was regarded as necessary to thaw the powder before placing it in the holes.

My first experiments were made in January, 1872. In making them the fact that the substance is a very poor conductor of heat was borne in mind, and in every case a long exposure to severe cold was regarded as essential to determinate results. It was also self-evident that the larger the surface exposed to the flame and shock of the fuze, the more likely would be the charge to detonate. Hence, I reasoned that the powder should be tested in a loose condition, rather than in the compacted state in which it is put upon the market.

Acting on these views some half pound charges, both loose and compacted into cartridges, were prepared and exposed for twenty-four hours to a temperature of 10° Fahr. Fuzes primed with 15 grains of fulminating mercury in copper caps were employed. In every case the *loose powder* exploded and the *compacted cartridges* failed.

Some compacted cartridges were next tried with the fuzes inserted in holes prepared before freezing, the whole lashed strongly with twine. The effect was to pulverize but not explode the material.

An ounce of soft dynamite was next detonated in contact with a frozen compacted cartridge, but failed to explode it.

Blocks of wood were next bored to a diameter of 1½ inches and charged, some with the dynamite solidly rammed and others with loose powder. Holes for receiving the fuzes were prepared, and the samples were solidly frozen. In every case the compacted dynamite failed and the loose powder exploded.

In the following winter (1873) the tests were continued, and an attempt was made to compare the explosive force of loose dynamite, frozen and soft.

Two pounds of dynamite No. 1 was placed loosely in a glass bottle with a hole prepared for a fuze of the usual kind. This bottle was then exposed for thirty-six hours to a temperature but little above zero, Fahr.; the fuze was inserted and the bottle was closed. It was then suspended under ice and exploded, causing a crater 12.8 feet in diameter. A precisely similar charge of soft dynamite, under identical circumstances as to thickness of ice (9 inches), submergence (3 feet), and depth of water (13.5 feet), caused a crater 13.4 feet in diameter.

In February, 1875, a frozen can, charged with 1 pound of loose dynamite, was slung in a hole through ice 11 inches thick, and left in position for seven days of very severe weather. It was then exploded without difficulty, giving a normal crater of 12.2 feet in diameter, the submergence being 3.1 feet, the depth of water 12 feet.

On October 29, 1874, a buoyant torpedo, charged with 100 pounds of dynamite, was planted in 32 feet of water. On January 23, 1875, it failed to explode. As soon as the ice permitted it was raised, and the reason was discovered. The fuze (20 grains) had been improperly placed at the very top of the fuze can, about an inch above the surface of the dynamite, and had exploded without firing the charge. The latter, still frozen, was not compacted, and a new fuze properly placed produced an explosion on the first trial. This is the only failure to explode frozen dynamite when in a loose state which has occurred in all my experience, and it should be attributed solely to the fault in loading. The fuze must be *in contact* with the explosive to be certain to ignite it, especially if frozen. In this instance the fuze tore a hole in the top of the can, but the shock was still insufficient to fire the charge.

On November 3, 187 , a *leaky* ground torpedo, containing 187 pounds of loose dynamite No. 1, was planted in 22 feet of water. A fuze, containing 20 grains of fulminating mercury in a copper cap, was placed in a water-tight tin can charged with 1 pound of loose dynamite No. 1, and the whole was bedded in the large charge. It remained in position until April 5, 1876, when the torpedo was exploded with full effect, the temperature of the water being still 40° Fahr. (or below the freezing point of nitro-glycerine). The dynamite must have been both wet and congealed.

On January 13, 1881, a ground mine, charged with 100 pounds of loose dynamite No. 1, and lying in the channel untouched since November 15, 1878, was fired without difficulty under thick ice.

In fine, at any temperature to which our submarine mines will be exposed, I consider that two service fuzes will certainly detonate our dynamite if in a loose state. Its high freezing point is a disadvantage, chiefly because when hardened and caked by frost it is not convenient for loading.

Effect of Long Storage.—The explosives at Willets Point are stored in the magazines of the fort, where during the winter the temperature falls sufficiently to freeze nitro-glycerine compounds. To determine whether any deterioration is caused by this action, and, incidentally, to compare dynamite No. 1 received at different dates, the following shots were fired in August, 1876.

Three lots were tested under identical circumstances—one received from the California Giant Powder Company in 1871, sent by rail across the continent; one received from the Atlantic Giant Powder Company in 1873; and one just received from the same company in 1876. The charges were each 3 pounds, contained in cans No. 1. They were fired in the 4-foot ring, submerged 35 feet in water 65 feet deep. The following table exhibits the results of the comparison, the mean pressure called for by the formula (equation 21) being 15,710 pounds per square inch:

Dynamite No. 1.—Effects of storage.

Lot of 1871.		Lot of 1873.		Lot of 1876.	
No. of shot.	Mean pressure. (Six gauges.)	No. of shot.	Mean pressure. (Six gauges.)	No. of shot.	Mean pressure. (Six gauges.)
	Pounds.		*Pounds.*		*Pounds.*
405	17,413	407	17,458	409	16,546
406	16,015	408	16,116	410	15,398
Mean.........	16,714	Mean.......	16,787	Mean.........	15,972

These figures certainly exhibit no evidence of deterioration after a storage of five years, the powder being exposed to alternate freezing and thawing, and they confirm the opinion, formed upon other grounds, that none is to be apprehended with the article supplied by these companies.

Air Space in Torpedo.—As already stated (p. 40), the tin cans used in these experiments were made of regular sizes, having a capacity for loose dynamite of 1, 3, 10, 20, and 50 pounds, respectively.

As a rule, the smallest can which would contain the given charge was selected; but a few shots were fired to determine the limits beyond which the void space could not be increased without reducing the intensity of action upon the gauges. The following table exhibits the results for a void space having about three times the volume of the charge:

Three-pound charges in four-foot ring.

CAN No. 1.					CAN No. 2.				
Explosive.	No. of shot.	Relative volume.		Obs. mean pressures. (Six gauges.)	Explosive.	No. of shot.	Relative volume.		Obs. mean pressures. (Six gauges.)
		Charge.	Void.				Charge.	Void.	
				Pounds.					*Pounds.*
Dynamite No. 1.........	359	1	0	15,441	Dynamite No. 1.......	200	1	3.3	15,786
Do................	196	1	0	17,005	Do..............	201	1	3.3	13,893
Do....	197	1	0	16,037	Do..............	202	1	3.3	17,650
Do................	198	1	0	16,765	Do..............	203	1	3.3	16,961
Do................	199	1	0	16,429	Do..........	213	1	3.3	17,366

Three-pound charges in four-foot ring—Continued.

Can No. 1.					Can No. 2.				
Explosive.	No. of shot.	Relative volume.		Obs. mean pressures. (Six gauges.)	Explosive.	No. of shot.	Relative volume.		Obs. mean pressures. (Six gauges.)
		Charge.	Void.				Charge.	Void.	
				Pounds.					*Pounds.*
Dynamite No. 1	405	1	0	17, 413	Dynamite No. 1	449	1	3. 3	16, 192
Do	406	1	0	16, 015	Do	450	1	3. 3	15, 317
Do	407	1	0	17, 458	Do	451	1	3. 3	15, 367
Do	408	1	0	16, 116	Mica powder	354	1	3. 3	10, 099
Do	409	1	0	16, 546	Dynamite No. 2	212	1	3. 3	12, 984
Do	410	1	0	15, 398					
Do	422	1	0	14, 623					
Do	423	1	0	14, 602					
Do	424	1	0	13, 850					
Do	425	1	0	15, 482					
Do	426	1	0	17, 209					
Do	427	1	0	15, 873					
Do	464	1	0	14, 577					
Do	467	1	0	16, 219					
Mica powder	364	1	0	11, 781					
Dynamite No. 2	337	1	0	13, 367					
Mean for dynamite No. 1				15, 831	Mean for dynamite No. 1				15, 625

It is evident from these figures that a void not exceeding three times the volume of the charge has no sensible effect on the intensity of action developed under water by explosive compounds. The influence of a still larger air space was next tested.

Dynamite No. 1.—*Eight-pound charges in eight-foot ring.*

Can No. 2.				Can No. 4.			
No. of shot.	Relative volume.		Obs. mean pressures. (Six gauges.)	No. of shot.	Relative volume.		Obs. mean pressures. (Six gauges.)
	Charge.	Void.			Charge.	Void.	
			Pounds.				*Pounds.*
489	1	0. 25	8, 872	494	1	5. 25	5, 541
490	1	0. 25	9, 370	495	1	5. 25	6, 534
491	1	0. 25	8, 382				
492	1	0. 25	7, 923				
493	1	0. 25	8, 224				
Mean			8, 554	Mean			6, 038

Here a marked loss of intensity is apparent. The safe limit of void space for small charges fired under water lies, therefore, between three and five times that of the charge.

It would appear altogether probable that as the size of the charge is increased this limit increases also, and hence that the void space necessary to give the requisite flotation to buoyant torpedoes does not lessen their destructive power. For ordinary mines of this character the void space is usually between two and three times that occupied by the charge.

A few experiments were made to ascertain whether an air space has a directive influence upon the blast, as was shown to be the case with explosive mixtures, but no such effect could be detected. The excessive quickness of the gas generation prevents any such tendency.

Material between the Charge and the Water.—Although an air cushion between the charge and the substance of which the torpedo is made causes, within certain limits, no loss of intensity of action in sub-aqueous explosions, it by no means follows that the gas strikes the water with the same kinetic energy whatever be the nature of this *interposed substance.* The first transformation into mechanical work occurs in its pulverization; and the total amount of energy thus absorbed must be deducted from that effective in giving the initial blow to the water, to be transmitted through it to the vessel. Experiment confirms these views, and shows that the loss in practice is very great if a thick, yielding material like wood be interposed.

There are available for this investigation 32 special shots with gun-cotton, 10 with dualin, and 8 with dynamite No. 1; some fired in wooden boxes 1 inch thick, some in wooden boxes 2 inches thick, and some in rubber bags. Those with gun-cotton will first be considered.

These 32 shots varied among themselves in respect to ring, charge, etc., and in order to make the comparison as comprehensive as possible it was deemed expedient to generalize them by deducing for each kind of case an independent value of K. The conclusions being thus based on the whole data would be more precise than if only the few shots fired under identical circumstances were selected for comparison. The tables render it easy for any one to apply the latter test if desired.

The method of deducing these values of K was the same already used for the shots fired in thin cases. No observations were rejected by Peirce's Criterion, and the resulting values of K were:

GUN-COTTON.

Two-inch wooden cases (24 shots), $K = 28.64 \pm 1.23$
One-inch wooden cases (6 shots), $K = 37.55 \pm 0.72$
Thin cases (equation (23)), $K = 47.28 \pm 0.65$
Rubber bags (2 shots), $K = 53.30 \pm 2.04$

Using the same analysis as in comparing the different explosives among themselves, these figures give for the relative intensity registered on the gauges in the horizontal plane containing the charge:

GUN-COTTON.

Two-inch wooden cases, $E = 46$. Relative intensity = 60
One-inch wooden cases, $E = 89$. Relative intensity = 80
Thin cases, $E = 135$. Relative intensity = 100
Rubber bags, $E = 164$. Relative intensity = 113

The data with dualin (2 shots in 1-inch, and 8 shots in 2-inch boxes) are insufficient to allow a distinction to be made between the two kinds of case. With dynamite, only 2-inch boxes were used. Applying the same analysis as above:

DUALIN.

Wooden cases (mostly 2-inch), $K = 35.83 \pm 1.63$. $E = 81$. Relative intensity = 53
Thin cases (equation (26)), $K = 67.70 \pm 1.08$. $E = 232$. Relative intensity = 100

DYNAMITE NO. 1.

Two-inch wooden cases, $K = 32.32 \pm 1.96$. $E = 64$. Relative intensity = 45
Thin cases (equation (16)), $K = 58.00$ $E = 186$. Relative intensity = 100
Rubber bags, $K = 69.01 \pm 2.38$. $E = 239$. Relative intensity = 119

From these figures it appears that small charges of these explosives, if fired under water, lose or gain according to the kind of envelope selected to contain them, the following percentage of the normal intensity they develop in thin cases:

Wooden cases, 2 inches thick,
- Gun-cotton loses 40 per cent.
- Dualin loses 47 per cent.
- Dynamite loses 55 per cent.

Wooden cases, 1 inch thick, gun-cotton loses 20 per cent.

Rubber bags,
- Gun-cotton gains 13 per cent.
- Dynamite gains 19 per cent.

These striking and important results of the analysis prove that the material of which a torpedo case for explosive compounds is made is an important matter. Any soft substance, like wood, deadens the shock upon the water in the same manner as if interposed between a hammer and anvil it would lessen the blow upon the latter. As already stated, such envelopes rise to the surface after the explosion in a form like match wood or sawdust, proving to the eye that immense energy has been expended in useless work.

The practical mistake of employing a weak iron receptacle for the charge, and enclosing it in a wooden jacket to give increased flotation and to serve as a buffer against the blows of vessels, is thus clearly shown. It is true that the percentage of reduction is probably much more for small than for large charges, but even with the latter the substance between the explosive and the water should be as thin as possible, in order to utilize the full intensity of the chemical reaction.

The following table exhibits the data used in this discussion, with the degree of accordance between the measurements and the formulæ constructed by substituting, for each kind of case, the above values of E in the general formula for explosive compounds, equation (36). Although some discrepancies naturally occur in an analysis based on the assumption that similar wooden boxes offer equal resistances, the table supplies ample evidence of the correctness of the foregoing conclusions:

Summary of experiments with wooden and rubber cases.

No. of shot.	Charge.		Submergence.	Case.	Ring.	Distance to gauges. (D)	Pressures per square inch. (P)		
	Kind.	Weight. (C)					Observed.	Computed.	Difference.
		Pounds.	*Feet.*		*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*
81	Gun-cotton	1	32	Wood, 2-inch	3	1. 12	4, 248	7, 869	— 3, 621
88	......do	2	33	......do	3	1. 12	13, 500	12, 490	+ 1, 010
74	......do	3	32	......do	3	1. 12	14, 725	16, 370	— 1, 645
90	......do	3	35	......do	3	1. 12	20, 724		+ 4, 354
165	......do	3	35	......do	3	1. 12	14, 434		— 1, 936
83	......do	4	33	......do	3	1. 12	20, 052	20, 140	— 88
166	......do	4	35	......do	3	1. 12	18, 795		— 1, 345
55	......do	6	32	......do	3	1. 12	20, 437	25, 980	— 5, 543
69	......do	1	33	......do	4	1. 62	3, 153	4, 712	— 1, 559
134	......do	1	35	......do	4	1. 62	3, 162		— 1, 550
135	......do	2	35	......do	4	1. 62	6, 777	7, 480	— 703
100	......do	3	35	......do	4	1. 62	8, 602	9, 802	— 1, 200
121	......do	3	35	......do	4	1. 62	8, 720		— 1, 082
101	......do	4	35	......do	4	1. 62	11, 334	11, 870	— 536
102	......do	4	35	......do	4	1. 62	13, 662		+ 1, 792
115	......do	4	35	......do	4	1. 62	14, 126		+ 2, 256
130	......do	4	35	......do	4	1. 62	15, 031		+ 3, 161
106	......do	5	35	......do	4	1. 62	17, 831	13, 777	+ 4, 054
107	......do	5	35	......do	4	1. 62	16, 552		+ 2, 775
61	......do	6	33	......do	4	1. 62	13, 180	15, 560	— 2, 380
63	......do	12	33	......do	4	1. 62	27, 298	24, 700	+ 2, 598
150	......do	3	35	......do	5	2. 12	8, 097	6, 739	+ 1, 358
15	......do	4	35	......do	5	2. 12	7, 666	8, 164	— 498
178	......do	4	68	......do	5	2. 12	7, 765		— 399
163	......do	1	35	Wood, 1-inch	3	1. 12	9, 631	9, 452	+ 179
164	......do	2	35	......do	3	1. 12	14, 913	15, 003	— 90
119	......do	1	35	......do	4	1. 62	6, 067	5, 660	+ 407
120	......do	2	35	......do	4	1. 62	10, 082	8, 984	+ 1, 098
148	......do	1	35	......do	5	2. 12	3, 307	3, 892	— 585
149	......do	2	35	......do	5	2. 12	5, 502	6, 177	— 675
403	......do	2. 4	35	Rubber bag	4	1. 62	12, 106	12, 810	— 704
411	......do	2. 4	35	......do	4	1. 62	13, 240		+ 430
67	Dualin	1	33	Wood, 2-inch	4	1. 62	4, 596	5, 489	— 893
122	......do	5	35	......do	4	1. 62	16, 713	16, 053	+ 660
123	......do	5	35	......do	4	1. 62	17, 263		+ 1, 210
62	......do	6	33	......do	4	1. 62	15, 240	18, 133	— 2, 893
116	......do	6. 5	35	......do	4	1. 62	24, 965	19, 123	+ 5, 842
177	......do	5	35	......do	5	2. 12	12, 930	11, 040	+ 1, 890
179	......do	5	68	......do	5	2. 12	12, 412		+ 1, 372
155	......do	6. 5	35	......do	5	2. 12	14, 059	13, 147	+ 912
57	......do	6	32	Wood, 1-inch	3	1. 12	22, 872	24, 050	— 1, 178
73	......do	12	33	......do	4	1. 62	26, 377	28, 770	— 2, 393
50	Dynamite No. 1	6	32	Wood, 2-inch	3	1. 12	27, 329	28, 230	— 901
68	......do	1	33	......do	4	1. 62	3, 934	5, 129	— 1, 195
103	......do	5	35	......do	4	1. 62	16, 909	14, 967	+ 1, 942
104	......do	5	35	......do	4	1. 62	16, 852		+ 1, 885
72	......do	6	33	......do	4	1. 62	14, 973	16, 903	— 1, 930
420	......do	3	35	Rubber bag	4	1. 62	18, 100	17, 665	+ 435
421	......do	3	35	......do	4	1. 62	16, 991		— 674
	Arithmetical means						13, 617	13, 547	1, 629

Sympathetic Explosion of Neighboring Mines.—The fact that explosive compounds, under certain conditions, are liable to be fired by the shock or vibration caused by an explosion in their vicinity has long been known, and many experiments have been made by Professor Abel and others to throw light upon these conditions.

At the great explosion at Hallett's Point, General Newton desired to make use of this principle in order to diminish the number of simultaneous ignitions to be effected by electricity; and the following interesting experiments were conducted by his assistant, Capt. James Mercur, Corps of Engineers, in September, 1876.

The explosive was dynamite No. 1, in the form of compacted cartridges. The charges were suspended from a horizontal iron bar by pine sticks, placed at known distances apart. The bar was suspended at known depths by buoys. The initial explosion was effected by a fulminating mercury fuze; and if the second charge was exploded by the shock, it "broomed" the end of its pine stick in a manner easily to be recognized In some of the experiments in which the second charge failed to explode, the case was broken and the nitro-glycerine was found to be leaking from the dynamite when the cartridge was recovered. The following are the results of these experiments, the value of P, computed by equation (21), being added for comparison:

Hallett's Point experiments upon sympathetic explosions.

Initial charge of dynamite No. 1.	Secondary charge of dynamite No. 1.					Result.
	Weight. (C)	Case.	Submergence. (S)	Distance. (D)	Mean pressure. (P)	
Pounds.	*Pounds.*		*Feet.*	*Feet.*	*Pounds.*	
1.0	1.0	Stout paper	6 to 30	18	262	Always exploded.
0.5	0.5	Rubber bag	6.0	12	290	Exploded.
0.5	0.5	......do	30.0	18	165	Do.
0.5	0.5	......do	4.5	18	165	Failed.
1.0	1.0	Brass, covered with paper 0.12 inches thick.	4.5	2	5,633	Exploded.
1.0	1.0	......do	3.0	5	1,569	Do.
1.0	1.0	......do	4.5	7	980	Failed.

These experiments prove, what might naturally be inferred, that the nature of the substance intervening between the water and the dynamite exercises an important influence upon the tendency of the latter to sympathetic explosion.

My attention was first drawn to this subject, as a matter of practical importance in submarine mining, by the rumors current in European journals, in 1874, that in certain experiments made by the Swedish Government a torpedo charged with 150 pounds of dynamite had ignited by sympathy two similar charges, each planted 200 feet from it and unconnected with it or with each other. All three charges were said to have been suspended 10 feet below the water surface. The mean pressure exerted by 150 pounds at 200 feet would, by my formula, be 254 pounds per square inch.

The nature of the torpedo case was not reported, nor the state of the dynamite, whether compacted or in loose powder; but the knowledge that Sweden had formerly adopted glass as a material (until it was found to be ruptured at a distance of 110 feet by a charge of 15 pounds of gun-cotton or dynamite submerged 8 feet), and had then experimented with very thin brass and iron cases, led me to suspect that the cases in this experiment might have been exceptionally weak; also that dynamite in compacted cartridges might have been used, which is not done in our service.

To test the matter in the most severe manner for our materials, I detonated on October 30, 1874, a charge of 100 pounds of dynamite No. 1 at a horizontal distance of 50 feet from a torpedo of the pattern of 1872 (wrought-iron one-eighth of an inch thick), also charged with 100 pounds of the same dynamite. Both torpedoes floated 8 feet above the bottom, in water 32 feet deep. The case was corrugated, but not broken by the shock, and no sympathetic explosion occurred. The mean pressure by my formula was 1,348 pounds.

To try the effect of crushing the case, I fired, on September 6, 1877, 200 pounds of dynamite No. 1, contained in a ground torpedo (model 1873-A), with a second torpedo of the same pattern, and containing the same charge, at a distance of 80 feet. The depth of water was 19 feet. That the case was crushed was made certain by the crushing of a third torpedo of the same kind planted, without a charge, at the same distance in another direction. In this experiment the second charge exploded, whether by the vibration acting upon it directly through the water, or by the impact of fragments of the broken iron, cannot of course be known. The mean pressure by equation (21) was 1,109 pounds.

Several other experiments, made from time to time, have suggested the conclusion that, unless the case be ruptured, dynamite No. 1 in loose powder is not liable to sympathetic explosion, even at distances much less than is proposed for the torpedo service. Such are the following:

A charge of 200 pounds of dynamite No. 1 was fired in a ground torpedo in water 20 feet deep. At horizontal distances of 20, 40, 60, 80, 100, and 120 feet, and resting on the bottom, were placed "detonators," so called. They consisted of cast-iron hollow spheres 1.25 inches thick, each just filled with 8 pounds of loose dynamite and hermetically closed. Although the explosion subjected them, respectively, to mean pressures of 7,718, 2,925, 1,658, 1,109, 818, and 628 pounds per square inch, none were broken or exploded by the shock.

This experiment was repeated under the same conditions, except that the detonators were suspended in wooden crows' feet, so as to hang just clear of the bottom, at distances of 30, 40, 60, 80, 100, and 120 feet, thus receiving mean pressures of 4,376, 2,925, 1,658, 1,109, 818, and 628 pounds per square inch, respectively. None were broken or exploded.

On another occasion a charge of 500 pounds of dynamite was exploded in 20 feet of water, submerged 13 feet below the surface. At a horizontal distance of 40 feet a detonator filled with 8 pounds of dynamite in loose powder was supported just above the bottom. It was unaffected by the shock, although subjected to a mean pressure of 5,150 pounds per square inch. Fuze cans of stout tin, each containing 1 pound of dynamite in loose powder, were suspended 1 foot below the surface, at the following horizontal distances from the great charge: 79, 94, 107, 110, 123, and 132 feet. Although subjected, respectively, to mean pressures of 2,087, 1,640, 1,368, 1,317, 1,126, and 1,021 pounds per square inch, none of them were exploded. The two nearest were much corrugated, the one at 79 feet being crushed inward but not broken open.

These trials led me to believe that no danger of sympathetic explosion need be apprehended with our dynamite and our patterns of submarine mines.

Some English results obtained in the Oberon trials suggest the same conclusion both for wet gun-cotton and for dynamite. In connection with the fourth experiment, a secondary charge of 100 pounds of Waltham Abbey disc gun-cotton saturated with about 30 per cent. of pure water, was placed in a service mine case on the bottom at 120 feet from the great mine containing 500 pounds of gun-cotton submerged 48 feet. Another secondary charge, consisting of 50 pounds of gun-cotton, was secured in a piece of netting and placed at the same distance also on the bottom. Neither were ignited by the explosion. At the fifth experiment three secondary charges were placed at 100 feet from the great mine, which contained 500 pounds of gun-cotton submerged 48 feet in water 66 feet deep. These secondary charges consisted of: (1) 50 pounds of Abel gun-cotton in a net; (2) 50 pounds of the same, wetted and enclosed in an iron case made for a 100-pound charge, the interspace being packed with wood; (3) two charges of dynamite, each of 25 pounds in a tin case. They were all suspended 10 feet below the surface, and none exploded when the great mine was fired.

After so much direct evidence, all opposed to the rumored Swedish results of which but few details had been made public, it appeared to be the part of wisdom to ignore them entirely. They were probably caused by some special conditions which would not be repeated in our service.

Nevertheless, the matter is so vitally important, and reasoning based on isolated facts not connected by known physical laws, is so unsatisfactory, that in the summer of 1879 a special series of experiments were undertaken, to throw, if possible, more light upon the phenomenon.

The plan devised for the Hallett's Point experiments commended itself by its simplicity, and by the valuable results it had already afforded; and the next step seemed to be to extend the investigation, so as (1) to develope the mathematical law connecting the size of the primary charge with its maximum exploding range; (2) to discover the influence exerted upon this range by varying, more systematically, the nature of the case containing the secondary charge; and (3) to test the effect of varying the density of the dynamite.

A slab of wrought-iron, 21 feet by 6 inches by 0.5 inches, was supported by two chains rising to a central ring in such a manner as to be readily slung, in a horizontal position about 3 feet below the water surface, from a crane on the end of a wharf at Willets Point. Four pressure gauges, of the pattern adopted in these investigations, were secured to this slab, about 4 feet apart, pointing downward and towards one of its ends. At this end a pine stick was attached, extending downward so that the primary charge could be lashed at a uniform depth of 5 feet below the water surface. A similar stick, to receive the secondary charge, was lashed at any selected point of the slab, the depth of submergence being in every case 5 feet. The original object of the gauges was to measure the energy developed by the explosions; but it was soon found that the shock transmitted through the stick and slab was sufficient to vitiate the results. As, however, they supplied a simple method of deciding with certainty whether the secondary charge had exploded or not, they were continued in use.

Forty-eight shots were fired with this apparatus, numbered 568 to 615, inclusive; and thirteen others were subsequently fired in like manner, but without gauges. These trials comprise experiments in which the secondary charge was inclosed in oiled paper; in three varieties of glass, viz, stout bottles from 0.1 to 0.2 inches thick, thin prescription vials about 0.04 inches thick, and very thin cylindrical jars about 2 inches in diameter with wide mouths closed by cork discs; in unsoldered baking-powder cans of thin (coke) tin; in small pine boxes 1 inch thick; and in stout, strongly brazed brass cans one-eighth of an inch thick (capacity about 1.5 pounds. In most of these envelopes dynamite No. 1 was tested in two series of trials—in one compacted to the density of an ordinary cartridge (specific gravity about 1.4), and in the other in the form of loose powder.

The immediate object proposed was to ascertain as nearly as possible the maximum distance at which primary charges, consisting of 1, ½, and ¼ pounds respectively, would explode the secondary charges. The distance between these two charges being in every case carefully measured before the apparatus was submerged, the results of the trials showed that the sympathetic influence, whatever it may be, is very uniform; and that its range may be fixed with certainty within a few inches, even when extending to 20 feet. The following table exhibits a summary of these experiments, the distances at which the secondary charges exploded being printed in full-faced type, and those at which they failed in Roman type:

Summary of sympathetic explosions.

WHARF TRIALS.

Primary charge of dynamite No. 1.	Distance to secondary charge of dynamite No. 1.												
	In paper.		In thin tin.		In thin glass cylinders.		In vials.	In thick bottles.		In pine.		In thick brass.	
	Compacted.	Loose.	Compacted.	Loose.	Compacted.	Loose.	Compacted.	Compacted.	Loose.	Compacted.	Loose.	Compacted.	Loose.
Pounds	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
1.00	20.65	20.65	**20.50**	20.55	**20.45**	20.45	19.7	20.35	....	11.55	....	12.40	....
1.00	**20.40**	**19.70**	....	....	....	18.85	15.3	17.10	....	10.20	....	10.40	....
1.00	**18.70**	**18.70**	....	....	....	11.75	12.6	12.50	....	8.55	....	7.70	....
1.00	**15.90**	....	....	....	....	8.50	**9.0**	10.15	....	**6.95**	....	6.35	....
1.00	....	....	....	....	....	**6.75**	....	10.04	....	**5.05**	....	**5.50**	....
1.00	....	....	....	....	....	....	....	7.30	....	....	....	**4.85**	....
1.00	....	....	....	....	....	....	....	5.10	....	....	....	....	....
1.00	....	....	....	....	....	....	....	**3.80**	....	....	....	....	....
0.50	19.80	....	**13.85**	10.60	....	....	....	....	....	....	....	5.20	3.50
0.50	15.35	....	....	7.75	....	....	....	....	....	....	....	4.20	3.00
0.50	14.90	....	....	6.70	....	....	....	....	....	....	....	**3.50**	2.00
0.5o	**13.95**	....	....	**5.80**	....	....	....	....	....	....	....	....	**1.25**
0.50	**13.85**	....	....	....	....	....	....	....	....	....	....	....	....
0.25	....	9.80	**10.35**	....	10.15	....	....	....	....	....	....	....	....
0.25	....	**9.35**	....	....	**9.35**	....	....	....	....	....	....	....	....
0.25	....	**8.80**	....	....	....	....	....	....	....	....	....	....	....

To extend these trials to still stronger envelopes, use was made of the "detonators" which had already been employed in previous trials. They consisted of cast-iron shells 1¼ inches thick, spherical in shape and prepared to contain 8 pounds of dynamite in loose powder. So large charges could not safely be exploded near the wharf, and they were accordingly suspended, 14 feet below the water surface, under a strong frame of 10-inch timber, having a clear space 10 by 11 feet in the middle.

The detonators were filled with compacted dynamite, giving a charge of 11.5 pounds. The primary charge consisted of 1 pound of dynamite contained in a stout tin fuze can of the pattern usually employed in these investigations. The depth of water was 49 feet. Explosions were had at the following distances, in no case causing a sympathetic explosion of the detonators, viz: 5.8, 4.8, 2.9, 1.7, and 0.5 feet. Even the last was not sufficient to crush the strong iron case.

Finally, the primary charge was lashed in absolute contact with the detonator, and caused its explosion; and the same result was obtained when the latter was charged with 8 pounds of loose dynamite, exactly filling the void.

The following experiments had been made previously with these detonators in air. They were laid on a solid rock, and half a pound of dynamite in a cloth bag was placed on top, without tamping, and fired with a detonating electrical fuze. The effect when the charge was loose was simply to crack open the shell like a melon, enabling the charge (8 pounds) to be recovered quite uninjured. This was repeated five times with the same result, the only variation being that occasionally a second explosion of 2 ounces was necessary to cause the cracked shell to fall apart. When, however, a *compacted* charge (11½ pounds) was used, a tremendous explosion occurred, throwing small fragments of the iron about 1,000 feet in every direction, and completely shattering the rock which supported the charge.

After a preliminary analysis of these experiments, three trials with service torpedoes were made in October, 1879, to verify the conclusions suggested.

The first shot was fired on October 1, the primary charge being a regular iron torpedo containing 100 pounds of dynamite No. 1, submerged 11 feet in water 20 feet deep. Around it were planted poles at various distances (accurately determined by triangulation), each supporting a small secondary charge at a depth of 5 feet below the surface. The following is a summary of the results of this experiment:

Sympathetic explosions.

PRIMARY CHARGE, 100 POUNDS OF DYNAMITE NO. 1.

Secondary charge, dynamite No. 1.			Distance from primary charge.	Remarks.
Envelope.	Weight.	Density.		
	Pounds.		*Feet.*	
Thin tin	1.75	Compacted	220	Top of can indented slightly.
Do	1.75	....do	209	Do.
Do	1.25	Loose	92	Can crushed; no explosion.
Do	1.25	....do	80	Do.
Thick bottle	1.00	Compacted	209	Bottle not injured.
Do	1.00	....do	194	Do.
Do	0.60	....do	187	Bottle cracked; no explosion.
Do	0.60	Loose	95	Bottle crushed; no explosion.
Do	0.75	....do	80	Do.
Do	0.75	....do	63	Do.
Stout brass	1.50	Compacted	60	Top and bottom of can indented.
Do	1.50	....do	50	Exploded.
Do	1.50	....do	42	Do.
Do	0.90	Loose	27	Do.
Do	0.90	....do	27	Do.
Do	0.90	....do	18	Do.

The second shot was fired on October 7, 1879. The arrangements were similar to the foregoing, except that the depth was 19 feet, and the submergence of the primary charge somewhat uncertain. It was intended to make this quantity 10 feet; but the torpedo seemed to be fouled in the electric cable when planted, and, as a burst of black mud appeared in the jet, this was doubtless the case. The secondary charges were only submerged 3.5 feet, the tide rising to a less height than usual. The following results were noted, and that some anomalous conditions affected them is apparent from a comparison of the column of remarks with that in the last table:

Sympathetic explosions.

PRIMARY CHARGE, 100 POUNDS OF DYNAMITE NO. 1.

Secondary charge, dyanmite No. 1.			Distance from primary charge.	Remarks.
Envelope.	Weight.	Density.		
	Pounds.		*Feet.*	
Thick glass	2.0	Compacted	157	Bottle not broken.
Do	1.9	do	140	Bottle cracked.
Do	1.9	do	115	Bottle not broken.
Do	1.2	Loose	76	Bottle crushed; no explosion.
Do	1.2	do	37	Do.
Do	1.2	do	16	Exploded.
Thin tin	1.2	Compacted	153	Can uninjured.
Do	1.2	do	133	Can slightly indented.
Do	1.2	Loose	45	Exploded.
Do	1.2	do	37	Do.

The third shot was fired on October 15, 1879. The conditions were similar to those of the first shot, except that the depth was 19 feet and the submergence of the torpedo 11 feet. The secondary charges were all submerged about 7 feet, except those in paper which were only 5 feet below the water surface. The following table exhibits the details of the experiments:

Sympathetic explosions.

PRIMARY CHARGE, 100 POUNDS OF DYNAMITE NO. 1.

Secondary charge, dynamite No. 1.			Distance from primary charge.	Remarks.
Envelope.	Weight.	Density.		
	Pounds.		*Feet.*	
Oiled paper	1.5	Compacted	208	Uninjured.
Do	1.5	do	175	Do.
Do	1.5	do	144	Do.
Thin vial	0.7	do	181	Not broken.
Do	0.7	do	152	Do.
Do	0.7	do	119	Crushed; no explosion.
Thick glass	2.0	do	49	Exploded.
Do	2.0	do	24	Do.
Do	1.2	Loose	28	Do.
Stout brass	0.9	do	32	Do.

The foregoing tables and records include all the new material collected; and the next point for consideration is the proper method of analysis.

The theory of sympathetic explosion is by no means well understood, but the explanation which seems to be most in accord with the known facts attributes the effect to a peculiar vibration produced by the primary explosion, which causes the atoms of the secondary charge to seek new chemical combinations. Different explosive substances differ greatly in their power of communicating such vibrations, which Professor Abel has shown to be quite independent of the absolute amount of heat and intensity of action developed; but for the *same* explosive it would seem probable that this power is a function of the kinetic energy which reaches the secondary charge and hence that the extreme range at which the effect can be produced is fixed by the minimum amount of this energy necessary to perform the peculiar atomic work in question. If so, designating (equation 16) this extreme range by Δ, and this minimum energy by W':

$$W' = \frac{KC}{(\Delta + 0.01)^{2.1}}$$

In this equation K is a known constant if we ignore the effect of angular changes of direction in the right line connecting the two charges; and the small constant in the denominator may be neglected. Hence by reduction:

$$\frac{\Delta}{\sqrt[2.1]{C}} = \sqrt[2.1]{\frac{K}{W'}} = B$$

If this theory be correct the quantity B in this equation should be constant for each particular envelope and density. The foregoing tables contain observations for determining this point; and, if the reasoning be verified, for fixing the limits within which the true value of B must lie for each kind of envelope and for the two conditions of the charge (compacted or loose).

The computation will consist in substituting successively for Δ the least distance at which the secondary charge failed, and the greatest distance at which it exploded, together with the corresponding value of C, and thus determining numbers respectively greater or less than the true value of B. The following table exhibits the results of this analysis applied to all the experiments with small primary charges:

Sympathetic explosions.

ANALYSIS OF WHARF AND RAFT EXPERIMENTS.

Primary charge of dynamite No. 1.	Secondary charge of dynamite No. 1.		No. of shots.	Greatest distance exploded.	Least distance failed.	Value of B lies between—		Remarks.
	Case.	State.						
Pounds.				*Feet.*	*Feet.*			
1.00	Oiled paper	Compact	4	20.40	20.65	20.4 and	20.7	
0.50	do	[illegible]	5	13.95	14.90	19.4	20.7	
1.00	do	[illegible]	3	19.70	20.65	19.7	20.7	
0.25	[illegible]	[illegible]	3	9.35	9.80	18.1	19.0	
1.00	[illegible]	[illegible]	1	20.50	......	20.5	....	
0.50	[illegible]	[illegible]	1	[illegible]	......	19.3	....	
0.25	[illegible]	[illegible]	1	[illegible]	......	20.0	....	
1.00	[illegible]	[illegible]	1	[illegible]	20.55	....	20.6	
0.50	[illegible]	[illegible]	4	[illegible]	6.70	8.1	9.3	
1.00	[illegible]	[illegible]	1	[illegible]	......	20.4	....	
0.25	[illegible]	[illegible]	2	[illegible]	10.15	18.1	19.6	
1.00	[illegible]	[illegible]	5	[illegible]	8.50	6.7	8.5	
1.00	[illegible]	[illegible]	4	[illegible]	12.60	9.0	12.6	
1.00	[illegible]	[illegible]	8	[illegible]	5.10	3.8	5.1	
[illegible]	[illegible]	[illegible]	5	[illegible]	8.55	6.9	8.6	
[illegible]	[illegible]	[illegible]	6	[illegible]	6.35	5.5	6.3	
[illegible]	[illegible]	[illegible]	3	[illegible]	4.20	5.0	5.8	
[illegible]	[illegible]	[illegible]	4	[illegible]	2.00	1.7	2.8	
[illegible]	[illegible]	[illegible]	7	[illegible]	0.50	0.0	0.5	Same when loose.

[illegible] alysis. Such are:

[illegible] Mallett's Point as to the influence

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exerted by the nature of the envelope are fully confirmed; *i. e.*, where the material composing the case offers a sensible interruption to the transmission of the normal vibrations the sympathetic range is surprisingly reduced. This appears from the relatively small values of B indicated for such envelopes, viz:

Charge compacted in thin glass vials	$9.0 < B < 12.6$
Charge compacted in thick glass bottles	$3.8 < B < 5.1$
Charge compacted in pine 1 inch thick	$6.9 < B < 8.6$
Charge compacted in stout brass	$5.0 < B < 6.3$
Charge compacted in iron, 1.25 inches	$0.0 < B < 0.5$

Moreover, it would appear from the crushing effects produced at ranges slightly greater than the maximum exploding limit that the phenomenon of sympathetic explosion rarely or never occurs with a resisting envelope, unless *the latter be crushed.*

II. The density of the dynamite is shown to be a very important element under certain circumstances. Thus, when the envelope offers no sensible resistance to the direct transmission of the kinetic energy, as in the case of the oiled paper, the unsoldered and very thin tin, and the thin glass cylinders, the value of B is sensibly constant if the dynamite be compacted; but if loose the protection against the compression due to a moderate head of water, afforded even by the two envelopes last named, reduces in a marked degree the range of the sympathetic action. This appears from the following comparison of the limits within which B is comprised in these two cases. Thus:

For compacted or loose dynamite in oiled paper, and for compacted dynamite in unsoldered thin tin, and in thin glass cylinders (21 observations).

$$\left\{\begin{matrix}20.4\\19.4\\19.7\\18.1\\20.5\\19.3\\20.0\\20.4\\18.1\end{matrix}\right\} < B < \left\{\begin{matrix}20.7\\20.7\\20.7\\19.0\\19.6\\ \\ \\ \\ \end{matrix}\right.$$

For loose dynamite in thin unsoldered tin, and in thin glass cylinders (9 observations).

$$\left\{\begin{matrix}8.1\\6.7\end{matrix}\right\} < B < \left\{\begin{matrix}9.3\\8.5\end{matrix}\right.$$

In other words, when the shock is directly transmitted to the dynamite the value of B lies between 18.1 and 20.7; but when the charge is so loosely packed as to permit motion among the particles, if the pressure of the water be removed even by an unresisting envelope this value lies between 6.7 and 9.3.

The protection probably afforded by slight possible motion among the particles of the explosive is also illustrated by the experiments with the stout brass cans. If compacted, the value of B lies between 5.0 and 6.3; but, if loose, it falls between the limits 1.7 and 2.8.

III. It would appear, from this discussion of the data with small primary charges, that the range at which sympathetic explosion should or should not occur may be predicted from the following formula by substituting for B the limiting values given above:

$$(34g) \qquad \Delta = B\sqrt[2.1]{C}$$

To test this conclusion the three large explosions above reported, and those given on page 123, will be analyzed. When the formula fails to predict the results correctly, the figures in the last two columns are printed in full-faced type, otherwise in Roman.

Sympathetic explosions.

ANALYSIS OF TRIALS WITH LARGE CHARGES.

Primary charge of dynamite No. 1.	Secondary charge of dynamite No. 1.	Theory indicates that the secondary charge should— Explode within—	Be doubtful between—	Fail beyond—	Experiment showed that the secondary charge— Exploded at—	Failed at—	Remarks.
Pounds.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
100	Compacted in stout brass cans....	45	45 and 56	56	50 42	60	
100	Loose in stout brass cans	15	15 25	25	**32** **27** **27** 18	(?)	
100	Compacted in thick bottles	34	34 46	46	**49** 24	209 194 187 157 140 115	
100	Loose in thick bottles	(?)	(?)	(?)	28 16	95 80 76 63 37	
100	Compacted in thin unsoldered tin.	162	162 185	185	(?)	220 209 **153** **133**	
100	Loose in thin unsoldered tin	60	60 83	83	45 37	92 80	
100	Compacted in thin vials...........	81	81 3	113	(?)	181 152 119	
100	Compacted in oiled paper.........	162	162 185	185	(?)	208 175 **144**	
200	Loose in small cast iron spheres, 1.25 inches thick.	0	0 6	6	(?)	120 120 100 100 80 80 60 60 40 40 20 30	
500	Loose in small cast-iron spheres, 1.25 inches thick.	0	0 10	10	(?)	40	
5[illegible]0	Loose in stout tin cans	33	33 54	54	(?)	132 107 123 94 110 79	

This table indicates that, out of fifty-five experiments on a large scale, the formula correctly predicts the result in all but seven instances, and that of these three failed only by 2 feet, 2 feet, and 3 feet, respectively, which are quite within the probable error of relative location of the primary and secondary charges. Of the four discrepancies remaining, one differed 7 in 25 feet; one, 9 in 162 feet; one, 29 in 162 feet; one, 18 in 162 feet; or, 28, 5, 18, and 11 per cent. of the predicted distances, respectively.

Remembering that the primary charges in these latter shots were from one hundred to five hundred times larger than the largest used in deducing the limiting values of B, and that the submergence was not increased proportionally with the charge, the weight of evidence would seem to be in favor of the truth of the general theory upon which the formula is based. In other words, it is a legitimate inference from these experiments that sympathetic explosions result from the transformation of a definite amount of kinetic energy, transmitted through the fluid, into atomic vibrations capable of inducing new chemical combinations in the molecules of nitro-glycerine.

The general practical conclusions to be drawn from this investigation seem, therefore, to be:

I. If the object be to avoid sympathetic explosions of dynamite No. 1, the secondary charge should be in a loose state, and should be inclosed in an envelope strong enough to resist the shock without crushing.. Under these conditions no induced explosion has ever occurred at Willets Point.

II. If the object be to cause sympathetic explosions, as for example in the simultaneous ignition of many sub-aqueous charges, the dynamite should be solidly compacted in a thin and elastic envelope, which will permit the water to press directly upon the secondary charge without wetting it. If the charges are to be kept submerged for long periods of time, large test tubes of the thinnest glass, projecting from the outer ends and containing dynamite very solidly rammed, might perhaps be better priming envelopes than paraffined paper. Of course, in all such operations the temperature of the water should be above 45° Fahr. to avoid congelation, which might materially modify the sensitiveness of the explosive.

Summary of Results with Explosive Compounds.—In summing up the conclusions to be drawn from the foregoing experiments with explosive compounds, several points merit attention.

I. Dynamite No. 1, compressed gun-cotton, and probably explosive gelatine, are all suitable explosives for the submarine mining service.

II. No advantage is derived from multiplying the points of ignition with either of them. One heavy detonation within the charge will develop its full power.

III. A priming charge of dynamite must be kept dry and in the state of loose powder to ensure the detonation of the main charge under all conditions of moisture and temperature. Hence, it should be inclosed in a separate case provided with mechanical devices for preventing packing.

IV. No advantage is secured by confining the charge in a strong case. Hence, the latter may be made to conform to the mechanical requirements of the problem; provided, however, that its material shall be hard and thin, so as not to absorb an unnecessary part of the energy of the charge.

V. The moderate air chamber within a buoyant torpedo, indispensable to the requisite flotation, is not objectionable; but it should not be larger than is necessary.

VI. No fear need be entertained of the sympathetic explosion of one charge from the explosion of its neighbor, or of a countermine, provided the case be of iron strong enough to resist rupture from the shock.

VII. No danger of deterioration after planting exists either with dynamite or compressed gun-cotton, when proper care has been observed in the manufacture and testing of the explosive.

VIII. Neither great depth of water nor great submergence is needful to develop the full force of explosive compounds. From 3 to 5 feet is sufficient for 100-pound charges.

IX. The following figures represent the relative intensity of action of the several explosives when fired under water:

Explosive gelatine	117
Dualin	111
Hercules powder No. 1	106
Dynamite No. 1	100
Rendrock	94
Gun-cotton	87
Dynamite No. 2	83
Mica powder No. 1	83
Hercules powder No. 2	83
Vulcan powder No. 2	82
Nitro-glycerine	81
Brugere powder	81
Vulcan powder No. 1	78
Electric powder No. 1	69
Designolle powder	68
Electric powder No. 2	62
Mica powder No. 2	62

X. Plate XV has been prepared to exhibit to the eye the relative intensity of action of small charges of dynamite No. 1, at any distance likely to be employed in submarine mining. When the absolute intensity needful to rupture a first-class ship of war has been determined, this diagram renders it easy to ascertain the dangerous range of any charge not exceeding 100 pounds. For larger charges this may be computed by equation (17).

BEST EXPLOSIVE FOR OUR SUBMARINE MINES.

In the foregoing analyses of our experiments with explosive mixtures and explosive compounds, will be found the results of extended and laborious investigations undertaken to provide data for a judicious selection of the explosive to be used in defending our harbors with submarine mines.

The merits to be sought in an explosive for this service are:

I. The greatest possible intensity of action when fired under water, in such envelopes as are suitable for submarine mines. This condition excludes all of the explosive mixtures; and, among the explosive compounds, limits the choice to explosive gelatine, dualin, hercules powder No. 1, dynamite No. 1, rendrock, and gun-cotton.

II. Retention of normal strength under the conditions incident to the service; viz, the lapse of time, alternate freezing and thawing, occasional wetting, and even saturation with water. By this standard dualin is far inferior to dynamite and gun-cotton, since it is dangerous when frozen, and when saturated loses half of its normal strength; while neither gun-cotton nor dynamite in loose powder are materially affected by water. Hercules powder and rendrock are quite excluded from the list by this condition, since their absorbents are soluble.

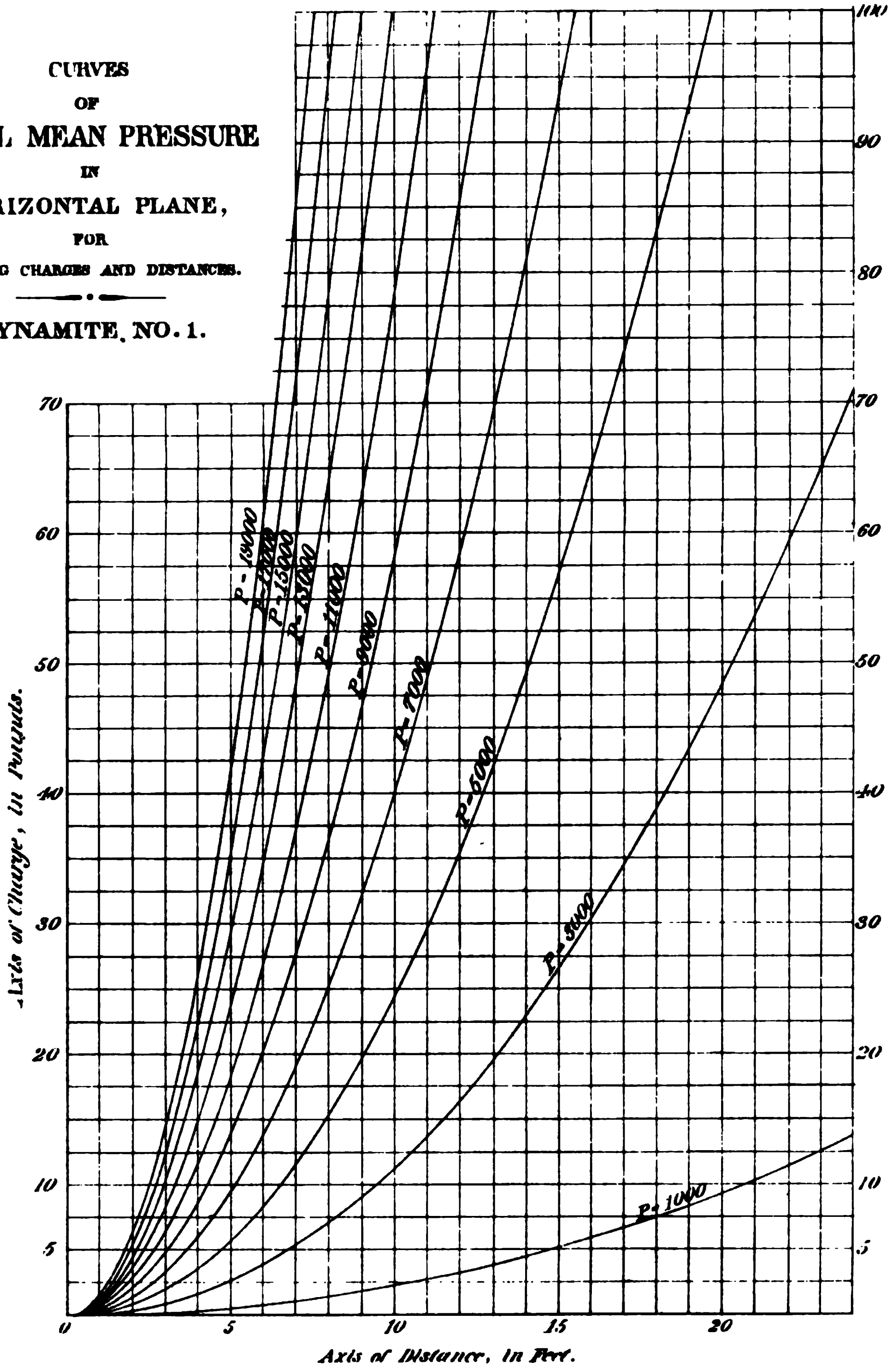
III. Convenience in loading—involving safety in transportation and in handling with ordinary roughness; a form which admits of ready insertion through a hole small enough to be easily rendered water-tight; and, lastly, a high density giving a small bulk. Gun-cotton when wet is quite safe; but its disc or slab form is inconvenient, and when granulated it is bulky. Dynamite with reasonable care is quite safe, but when handled by men not accustomed to its use it often causes headaches. In respect to density, even in the shape of loose powder, it has the advantage over either of the others, and it can be readily inserted through a hole 3 inches in diameter. Dualin is unsafe when frozen; is as objectionable as dynamite in respect to headaches; and is also quite bulky. By this standard, therefore, it again appears that dualin is decidedly inferior to the other two.

IV. Market facilities. It is undesirable that a large supply of any of these high explosives should be kept in store in our forts during peace. Hence, to be readily obtainable in the market in large quantities, is no small merit. Gun-cotton is not manufactured in this country. Dualin is to be had from only one party; and its manufacture is shrouded with so much mystery, and is so often varied, that the product fails to command the confidence of experts. Dynamite is manufactured largely and at reasonable cost by two responsible companies, one near San Francisco, and the other near New York City; and a good article could be supplied as fast as the Government would require it, even in an emergency.

CURVES
OF
EQUAL MEAN PRESSURE
IN
HORIZONTAL PLANE,
FOR
VARYING CHARGES AND DISTANCES.

◆

DYNAMITE, NO. 1.



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A careful consideration of these several advantages and disadvantages has led the Board of Engineers to the conclusion that dynamite No. 1 should be adopted, provisionally, as the best explosive for our service; and our experiments to determine the destructive range of torpedoes against shipping, the effect of explosions upon neighboring mines, etc., have accordingly been made with that compound exclusively. Extended trials and much experience have developed nothing to throw doubt upon the wisdom of that selection, but it is held always open to reconsideration. As new explosives appear they are carefully tested; and it is not improbable that the trials now in hand with explosive gelatine may show it to be a formidable rival.

DESTRUCTIVE EFFECTS OF SUB-AQUEOUS EXPLOSIONS.

The investigations already reported have supplied the information needful for a judicious selection of the explosive best suited for use in defending our harbors, and have revealed important points to be observed in designing suitable patterns of buoyant and ground torpedoes. It remains to consider what has been done to determine the absolute intensity of action requisite to disable a ship-of-war of the best modern type.

The expense attending experiments upon a target perfectly representing such a vessel would far exceed the funds available in these trials; and indirect methods have, therefore, been employed from necessity. Fortunately, the Oberon and other trials were fully reported in the European journals, and by the aid of our formulæ can be made of much value in supplementing these data.

Before considering the main question, a few incidental points developed in this investigation will be noticed.

Depressions in Target.—A curious result was discovered in this connection, which may perhaps prove of some practical value

In two of the experiments with the iron target (shot 394 and 395) one-half of the rods holding the gauges were shortened, so that the pistons were placed 2.3 feet instead of 0.1 of a foot above the plane of the bottom of the target. The tubes containing the gauges were 4 inches in internal diameter. This withdrawal of the gauges into a cylindrical recess in the surface exposed to the shock, exerted an extraordinary effect upon the energy and mean pressure registered upon the leads.

Both shots consisted of 100 pounds of dynamite No. 1 exploded vertically under an edge of the target (20 feet square). No. 394 was submerged 27.5 feet below the plane of the bottom; and No. 395, 17.5 feet—the draft being 2.5 feet. The following are the mean intensities registered on the gauges—full details in other respects being given in Appendix C.

Shot 394. Eight long gauges. $P = 2898$. Eight short gauges. $P = 1167$.
395. Eight long gauges. $P = 3495$. Eight short gauges. $P = 1473$.

The enormous reduction indicated by these figures suggested that the small hole in the screw plug of the gauges in which the pistons move (Plate I) might perhaps exert a similar influence; and thus render a special correction necessary whenever leads of different length were used.

To test this matter some special pistons were provided for use in the No. 1 gauge (area of piston head, 0 1 inch). The usual length of this piston is 1.5 inches. The first new length tested was 2 inches, which just left room for a gas-check when a 0.4 lead was used; thus filling the cylindrical hole (0.5 inches long) existing between the piston head and the face of the screw plug. Three shots (Nos. 422, 423, and 424) were fired with these new pistons. The charge was 3 pounds of dynamite in the 4-foot ring, submerged 35 feet in 62 feet of water. No indication of a pressure greater than usual was obtained, as may be seen by referring to the table on page 76.

Three shots (Nos. 425, 426, and 427) were then fired with the alternate gauges fitted as just described, the others being of the usual pattern. The charge, ring, etc., remained unchanged. Result:

Mean of 9 long piston gauges: P = 16,234.
Mean of 9 short piston gauges: P = 16,322.

To make the test as complete as possible the smallest and shortest lead (0.3 inches in diameter and 0.5 inches long) was next tried in a similar manner, the charge being 1 pound of dynamite No. 1 in the 4-foot ring, submerged 5 feet in 70 feet of water. Shots Nos. 455, 456, and 457 were fired with all the pistons 2.35 inches long, which brought the ends flush with the face of the screw-plug. By reference to the table on page 75, it will be seen that the indicated pressures did not differ from those obtained with the usual length, which leaves a cylindrical hole 0.85 inches long over the piston head.

Three shots (Nos. 452, 453, and 454) were then fired with the alternate pistons 2.35 inches and 1.5 inches long, respectively, the shots being the same in all other respects as the last. Result:

Mean of 9 long piston gauges: P = 8,018.
Mean of 9 short piston gauges: P = 8,742.

In fine, these trials proved conclusively that no error due to the length of the hole over the piston head varying with leads of different lengths need be apprehended; but the effect of the larger openings in the iron target is none the less noteworthy. It may, perhaps, suggest some expedient for protecting the feed and escape pipes against the local injuries to which the Oberon experiments have shown them to be peculiarly liable when a large torpedo is exploded in the vicinity.

Effect of Recoil in Target.—That the immense weight and stability of an armored ship-of-war will increase the intensity of action developed by a sub-aqueous explosion much beyond what is registered upon a comparatively light and movable target was fully recognized in planning our torpedo experiments to determine destructive range; indeed, this is the great practical difficulty in conducting such trials, and even in the case of the Oberon it was not entirely overcome.

The subject will again be considered in connection with our experiments upon the wooden and iron targets. Here it is mentioned only to introduce a few special ring trials, suggested by some surprising results obtained with the latter, which indicated a numerical value for this reduction so greatly exceeding what was expected as to demand special investigation.

These trials were made in connection with shots Nos. 483 to 488, inclusive, fired in the 3-foot ring, submerged 33 feet in water 70 feet deep. The explosive was dynamite No. 1, and the charges varied from 1 to 3 pounds

The object was to expose to the action of the same explosion one fixed and one movable gauge, side by side, and thus to determine the absolute reduction in mean pressure due to recession from the locus of the charge.

The extra gauge was secured in a socket made to be used inside gunpowder charges. It was held in place alongside of gauge No. 3 in the same horizontal plane, and directed toward the can containing the charge. The attachment to the ring was by a stout 2-inch pine strap, fitted over the socket of No. 3, and securely lashed in position. To recover the apparatus, it was shackled to the guard ring by a 10-foot length of inch wire rope. Thus the two gauges, both in distance and direction, were similarly placed in respect to the can, the only difference being that No. 3 received the full shock, while the extra gauge was shot off into the water as soon as the wooden strap was disrupted The following are the details of the six shots, the means of the six ring gauges being added as a check upon gauge No. 3, which should register sensibly the same intensity of action:

Fixed and movable gauges.

DYNAMITE NO. 1.

No. of shot.	Charge.	Mean pressure per square inch registered by—			Absorbed in motion, as shown by—		Remarks.
		6 gauges.	Gauge No. 3.	Mov gauge.	6 gauges.	Gauge No. 3.	
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	
483	1	13,029	12,851	2,362	10,667	10,489	Wooden strap pulverized by explosion—fragments rising for over a minute.
484	1	12,375	12,578	4,264	8,111	8,314	
485	2	20,075	17,665	Lost.	......	......	
486	2	19,557	19,335	2,261	17,296	17,074	
487	3	25,696	25,382	2,855	22,841	22,527	
488	3	25,106	27,120	2,362	22,744	24,758	

The absolute reduction of mean pressure due to motion communicated to the whole movable apparatus was thus *several hundred per cent.* of that expended in shortening the lead; *i. e.*, in performing work destructive to the body receiving the blow

But these data exhibit a still more surprising fact, viz, that within the limits and under the conditions of the experiments an increase of charge causes no increased pressure upon the body receiving the blow, provided the latter can yield. The whole energy due to the increase of charge takes the kinetic form, and is gradually absorbed by the resistance of the water to the passage of the gauge and socket through it; in other words, a certain amount of work is required to disrupt the wooden attachments, and of course is registered upon the lead; but since this amount is sensibly the same, whatever be the charge, no more can be utilized or registered.

These facts exhibit, in a forcible manner, the immense importance of considering the element of rigidity in all experiments upon the destructive range of torpedoes. It will be remembered that the same thing was indicated by the discussion of the buoy and shackle data for explosive mixtures* on page 66, and it will soon be again confirmed by the shots fired under the target.

Experiments Under Ice.—In describing the phenomena attending a sub-aqueous explosion it has been explained that a dome, often of considerable diameter, is formed first, and that the great jet of water and gas bursts upwards from its centre. When fired under ice these effects are self-registered. The diameter of the jet is shown by a circular space of clear water, from which the ice has been driven into the air; and the locus of the dome is indicated by concentric circular cracks connected by radial

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* With explosive compounds the charges used in the experiments were necessarily so small that this normal effect was reversed. Instead of being thrown bodily into the air with the water, the buoy was only raised 3 or 4 feet by the molecular shock, and in sinking received the full initial blow from the ascending gas chamber and upward burst of water. The effect was to make the buoy gauge register absolutely a larger pressure than the shackle gauge, which being near the charge received the shock of the gas chamber as it was dragged upward by the rise of the buoy.

This anomaly appears quite uniformly in all the ring shots with explosive compounds, but as the fact has no important practical bearing it has not been considered necessary to give a tabular exhibit here, especially as the data in the appendix afford every facility for examining the matter in detail. The following figures represent the grand mean of the first 280 shots with every variety of explosive compound. The computed pressures, added for comparison, were found in each case by the proper formulæ, and a mean was then taken of the whole.

Mean charge in pounds (280 shots)	3.4.
Mean interval in seconds between explosion and gas appearance	5.2.
Mean pressure in pounds by shackle gauge, distant 14 feet from charge, observed	874.
Mean pressure in pounds by shackle gauge, distant 14 feet from charge, computed	789.
Mean pressure in pounds by buoy gauge, distant 28.1 feet from charge, observed	1,075.
Mean pressure in pounds by buoy gauge, distant 28.1 feet from charge, computed	332.

It appears from these figures that the shackle gauge, which is subjected to the usual vertical action of the charge ($\vartheta = 180^\circ$), corresponds well with the indications of the formulæ, and hence it may, perhaps, be inferred that the discrepancy indicated by the buoy gauge is a rough measure of the effect of the second blow. That such duplicate blows are registered on my gauges in sub aqueous explosions (although not with the Rodman apparatus in cannon) was shown by a few special shots fired to test the matter. The following figures exhibit the results, the No. 1 gauge and 0.4 leads being used in the 4-foot ring, with a charge of 3 pounds of dynamite No. 1, submerged 35 feet in water 50 feet deep.

	Inches.
Shot 164.—Lead shortening (mean of six gauges)	0.156.
Shot 165.—Same leads, additional shortening	0.128.
Shot 166.—Same leads, additional shortening	0.091.
Shot 167.—Lead shortening (mean of six gauges)	0.173.
Shot 168.—Same leads, additional shortening	0.120.
Shot 169.—Same leads, additional shortening	0.100.

A tendency toward this peculiar anomaly exhibited by small charges acting upon distant gauges vertically over them is shown in a few of the wooden target shots soon to be considered.

cracks. In shallow water a second swell often appears at the hole and deposits muddy water over the surrounding ice; indeed, material from the bottom is usually thrown out.

If the charge be submerged too deeply the diameter of the jet crater is reduced and may even become zero; if it be placed too near the surface a reduction is also produced both in the jet crater and in the dome crater; in other words, for each charge there is a particular submergence at which it performs its maximum work in disrupting the ice, but with explosive compounds this submergence is slight.

Early in these experiments it was considered that valuable information as to the laws governing the transmission of the destructive forces developed by sub-aqueous explosions might be obtained by taking advantage of the facts above recited. Trials under ice with various explosives were accordingly made during favorable seasons, and by them the data set forth in the following table were secured.

The experiments were made by cutting a small hole in the ice; inserting the torpedo so weighted as to sink; and supporting it at a known depth by a rope attached to a stick laid over the hole. The explosion was usually effected at once, with the hole open; but sometimes the latter was covered by a large cake of ice, and sometimes the charge was left in position until ice, naturally formed, had closed the orifice. After firing, careful measurements of the crater radius, which is always remarkably uniform, were made. The following table exhibits the data secured in this manner in the years 1871, 1873, 1875, and 1879:

Summary of experiments under ice.

No. of shot.	Date.	Charge			Fuses.		Case.	Depth of water.	Thickness of ice.	Crater.	
		Kind.	Weight. (C)	Sub. (S)	No.	R.				r	r^2.
			Pounds.	*Feet.*		*Inches.*		*Feet.*	*Inches.*	*Feet.*	*Feet.*
1	February 6, 1871	Mortar powder ...	2.0	13.0	3	1.68	Bottle...........	13.0	6.0	0.0	0.0
2	....do..........	....do............	2.0	3.0	3	1.68	....do...........	13.0	6.0	3.5	12.2
3	....do..........	....do............	50.0	15.0	10	3.30	Wooden torpedo .	15.0	6.0	17.5	306.2
4	February 7, 1871	....do............	100.0	15.0	20	3.30	....do...........	22.0	7.0	21.0	441.0
5	... do..........	....do............	50.0	Surface.	10	3.30	....do...........	....	7.0	2.5	6.2
6	....do..........	....do............	50.0	Surface.	10	3.30	....do...........	....	7.0	2.5	6.2
7	....do..........	....do............	7.5	5.0	4	2.38	Demijohn........	11.5	7.0	9.0	81.0
8	January 8, 1873	Dynamite, soft....	2.0	13.5	1	....	Bottle...........	13.5	6.5	0.0	0.0
9	....do..........	... do............	2.0	3.0	1	....	....do...........	14.0	6.5	6.8	46.2
10	....do..........	....do............	7.5	5.0	1	....	Can No. 2........	11.5	6.5	11.5	132.2
11	January 10, 1873	....do............	2.0	7.2	1	....	Bottle...........	13.5	8.5	0.0	0.0
12	....do..........	....do............	2.0	8.2	1	....	....do...........	12.0	8.5	0.0	0.0
13	....do..........	.. do............	2.0	3.0	1	....	....do...........	13.2	8.5	6.7	44.9
14	....do..........	Dynamite, frozen .	2.0	3.0	1	....	....do...........	13.5	8.5	6.4	41.0
17	January 15, 1873	... do............	2.0	9.2	1	....	....do...........	11.0	9.0*	0.0	0.0
18	....do..........	Dynamite, soft....	2.0	5.0	1	....	....do...........	12.0	9.0*	8.2	67.2
19	February 9, 1875	Dynamite, frozen .	1.0	3.4	1	....	Fuze can.........	12.0	11.0†	6.1	37.2
20	January 31, 1879	....do............	10.0	3.5	2	....	Can No. 2........	10.5	8.5	13.8	190.4
21	....do..........	....do............	10.0	9.3	2	....	....do...........	10.5	8.5	10.3	106.1
22	....do..........	....do............	5.0	5.3	2	....	....do...........	10.0	8.5	9.4	88.4

* Hole covered.

† Hole frozen over.

Summary of experiments under ice—Continued.

No. of shot.	Date.	Charge.			Fuzes.		Case.	Depth of water.	Thickness of ice.	Crater.	
		Kind.	Weight. (C)	Sub. (S)	No.	R.				r	r^2.
			Pounds.	*Feet.*		*Inches.*		*Feet.*	*Inches.*	*Feet.*	*Feet.*
23	January 31, 1879	Dynamite, frozen .	5. 0.	9. 0	2	....	Can No. 2	10 0	8. 5	5. 9	34. 8
24	....do	....do	5. 0	2. 0	2	....	....do.............	10. 0	8. 5	9. 2	84. 6
16	January 10, 1873	Dualin, frozen	2. 0	3. 0	1	....	Can No. 1	12. 5	8. 5	7. 1	50. 4
15	....do	Gun-cotton	2. 0	3. 0	4	....	....do.............	10. 5	8. 5	6. 7	44. 9

This table gives information upon several points of practical interest.

I. It affords data for comparing the efficiency of different explosives in opening a channel of escape for a vessel frozen in position. For this purpose the square of the crater radius for like charges appears to be the best attainable gauge of absolute merit—the relative merit, of course, depending also upon the cost.

For example, shots Nos. 7 and 10 were fired respectively with mortar powder and dynamite No. 1; the charge in each case was 7.5 pounds; the submergence was 5 feet; the other conditions were practically identical, and such as are likely to be encountered in practice. The squares of the crater radii were, respectively, 81 and 132.2 square feet. Since dynamite is between three and four times as costly per pound as mortar powder, these figures show that the latter should have the preference for such work. By sinking several 10-pound charges 18 feet apart upon the line to be opened, and exploding them simultaneously, a channel from 16 to 18 feet wide can be rapidly formed. It should be borne in mind that mortar powder does not break the ice in so small fragments as dynamite, and hence that the passage is more choked with floating *débris* than when the stronger explosive is used.

II. The table affords a rough gauge of the relative strength of the different explosive compounds, both in a frozen and soft state, and as compared with each other.

For example, the following shots were fired with a uniform submergence of 3 feet, the charge being 2 pounds, and the other conditions being similar. The relative strength is inferred from the ratio of the squares of the crater radii:

	Square crater radii.	Relative strength.
Shot No. 2.—Mortar powder....................................	12. 2;	1. 00.
Shot No. 9.—Dynamite No. 1, soft	46. 2;	3. 74.
Shot No. 13.—Dynamite No. 1, soft	44. 9;	
Shot No. 14.—Dynamite No. 1, frozen	41. 0;	3. 36.
Shot No. 16.—Dualin, frozen	50. 4;	4. 13.
Shot No. 15.—Compressed gun-cotton..................................	44. 9;	3. 60.

III. These data, with the formulæ already given, render it easy to subject the whole subject of explosions under ice to a mathematical analysis—with a view to generalizing the phenomena observed, and thus to deriving from them indications not without value in connection with the general investigation of sub-aqueous explosions. The method adopted for this analysis has been the following:

The varying conditions inseparable from the explosion of gunpowder under water decided me to restrict the study to shots fired with explosive compounds.

The edges of the ice marking the crater are always so sharply defined and so regular, that it appeared reasonable to suppose *the mean pressure upon that line to be nearly constant, however much the charges and submergences might vary.* The observations established that this was a legitimate inference, as will soon appear.

From the triangle formed by a line (D) drawn from the centre of the charge to any point of this circle of rupture, the crater radius (r) and the vertical line from the centre of the charge to the surface (S), the following equations can be derived:

$$r^2 = D^2 - S^2.$$

$$D = \frac{S}{\cos. (180^\circ - \vartheta)} \tag{37}$$

Whence:

$$r = \frac{S}{\cot. (180^\circ - \vartheta)} \tag{38}$$

The general equation for explosive compounds (page 109) is:

$$P = \sqrt[3]{\left(\frac{6636\ (\vartheta + E)\ C}{(D + 0.01)^{2.1}}\right)^2} \tag{36}$$

Combining this equation with equation (37); neglecting the second term of the denominator, as too small to be regarded in this discussion; and reducing, the following equation results:

$$(\vartheta + E) \cos.^{2.1} (180^\circ - \vartheta) = \frac{\sqrt{P^3}\ S^{2.1}}{6636\ C}$$

It only remains to determine the numerical value of P in this equation. In the following table, fourteen values derived from the observations are given; but as two shots (Nos. 18 and 19) differ from the rest by having the small hole over the charge plugged, they have been omitted in framing the formulæ; and the mean of the remaining twelve, or $\sqrt{P^3} = 69{,}605 \pm 2095$, *i. e.*, $P = 1692$, was adopted, giving:

$$(\vartheta + E) \cos.^{2.1} (180^\circ - \vartheta) = \frac{10.49\ S^{2.1}}{C} \tag{39}$$

The following table exhibits a comparison between the values of the crater radius computed by equations (38) and (39) and those found by the actual trials above reported. The accordance is extraordinary, and illustrates the precision and value of the general formula for explosive compounds. It will be noticed that allowing the small hole (about 9 inches in diameter) through which the charge had been submerged to freeze solidly, or simply covering it by a heavy cake of ice, increased the crater radius 2 or 3 feet, in shots Nos. 19 and 18.

Analysis of experiments under ice.

EXPLOSIVE COMPOUNDS.

No. of shot.	Charge.			Thickness of ice.	Distance from charge to edge. (D)	Mean pressure per square inch.		Crater radius. (r)			Remarks.
	Kind.	Weight. (C)	Sub. (S)			At edge. (P)	Vertically over charge.	Obs.	Comp.	Diff.	
		Pounds.	*Feet.*	*Inches.*	*Feet.*	*Pounds.*	*Pounds.*	*Feet.*	*Feet.*	*Feet*	
8	Dynamite, soft....	2	13.5	6.5	13.5	......	749	0.0	0.0	0.0	
9	....do	2	3.0	6.5	7.4	1,513	6,130	6.8	6.2	+ 0.6	
10	....do	7.5	5.0	6.5	12.5	1,755	7,366	11.5	11.9	— 0.4	
11	....do	2	7.2	8.5	7.2	1,805	1,805	0.1	0.4	— 0.3	Lim. of strength
12	....do	2	8.2	8.5	8.2	......	1,505	0.0	0.0	0.0	
13	....do	2	3.0	8.5	7.3	1,539	6,130	6.7	6.2	+ 0.5	
14	Dynamite, frozen..	2	3.0	8.5	7.1	1,626	6,130	6.4	6.2	+ 0.2	
17	... do	2	9.2	9+	9.2	......	1,281	0.0	0.0	0.0	Hole covered.
18	Dynamite, soft....	2	5.0	9+	9.6	1,074	3,004	8.2	5.0	+ 3.2	Do.
16	Dualin, frozen.....	2	3.0	8.5	7.7	1,577	6,634	7.1	6.7	+ 0.4	
15	Gun-cotton	2	3.0	8.5	7.3	1,359	5,571	6.7	5.5	+ 1.2	
19	Dynamite, frozen..	1	3.4	11	7.0	1,053	3,244	6.1	3.8	+ 2.3	Hole frozen.
20	....do	10	3.5	8.5	14.2	1,748	17,390	13.8	14.1	— 0.3	
21	....do	10	9.8	8.5	13.9	1,945	7,950	10.3	11.9	— 1.6	
22	....do	5	5.3	8.5	10.8	1,672	5,116	9.4	9.3	+ 0.1	
23	....do	5	9.0	8.5	10.8	1,767	2,434	5.9	6.7	— 0.8	
24	....do	5	2.0	8.5	9.4	1,949	19,880	9.2	10.2	— 1.0	
Arithmetical sums, excluding shots Nos. 17, 18, and 19................................								93.9	95.3	7.4	

The above formulæ furnish a complete solution of problems involving the charge, submergence and crater radius as variables—the computation being made by the method of successive approximations. Thus, to find the crater radius corresponding to a known charge and submergence, find by trial the value of ϑ in equation (39); substitute it in equation (38) and find r.

To find the charge required for a given submergence and crater radius, find ϑ from equation (38); substitute this value in equation (39), and find C.

To find the submergence required for a given charge and crater radius, assume a value for ϑ in equation (38), and find S; substitute the same value of ϑ in equation (39), and find S. If these values be identical, S is correct; if not, repeat the operation until such accordance is obtained.

It might appear, by applying the usual methods of the differential calculus to these formulæ, that it would be possible to find the submergence of a given charge which corresponds to the maximum crater radius; and hence to determine the most economical use of the explosive. If this be done, it will be found that the required condition is:

$$\vartheta = -\mathrm{E}.$$

which is fulfilled when:

$$\mathrm{S} = 0.$$

$$r = \mathrm{D}.$$

In other words, the charge must be bedded in the ice itself. This is not a true practical result. It arises, partly because no function of S appears in the general formula for explosive compounds, and hence the analysis ignores the slight submergence needful to develop the force of the explosion; and partly because the general theory supposes the shock to be transmitted through water, not through ice. In other words, the formulæ are not applicable to these conditions of a theoretical maximum. As a matter of fact, however, the submergence must be very slight to develop the best results with explosive compounds—as may easily be seen from the last table.

IV. The most important deduction from these experiments, so far as the general investigation is concerned, is the fact that the quantity P proves to be a trustworthy measure of the *rupturing power* of a sub-aqueous explosion. The ice yields when subjected to a certain definite strain, of which this is a true gauge. Hence, we may also expect to find it a gauge of the strains to which the hull of a ship must yield.

Experiments with the Targets.—The two targets designed and constructed for these investigations, one of wood and the other of iron, have already (page 35) been fully described. They were neither of them what was desired; but the limited funds available compelled a rigid economy; and, supplemented by the elaborate analysis of the problem already reported, it was believed that they could be made to serve the needful purpose.

The experiments with the wooden target were merely tentative, to supply data for use in conducting the trials with the more perfect model in iron. Twenty-eight shots were fired under it, mostly at too great distances to produce any injurious effect. Indeed, in the first eight shots the target was used simply as a buoy to sustain the ring at great depths.

The gauges were held in position by the same iron rods used with the iron target; which being made for gauge No. 1 would not fit the larger and more sensitive patterns. Hence several of the distant shots gave no measureable shortenings of the leads. The following table exhibits the details of the several shots under the wooden target, the explosive being dynamite No 1. It will be remembered that its weight was 12 tons; and that in No. 371 and subsequent shots, it was lashed down as already described. The table is arranged according to the charge, not according to the sequence of shots as fired, which is sufficiently indicated by their numbers:

Experiments with wooden target.

No. of shot.	Charge.		Mean distance to gauges. (D)	Pressure per square inch. (P) (Mean of eight gauges.)			Remarks.
	Weight. (C)	Sub. (S)		Observed.	Comp.	Difference.	
	Pounds.	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*	
294	5	100	98. 2	Off scale	85	......	Bubbles rose in 2 or 3 minutes.
295	5	80	78. 2	..do ...	118	......	Bubbles rose in a minute 20 feet from target.
296	5	70	68. 2	..do ...	142	......	Upflow of water near target in about a minute.
297	5	60	58. 3	..do ...	175	......	Upflow of water in 20 seconds.
298	5	50	48. 4	..do ...	228	......	Upflow of water in a few seconds.
299	5	40	38. 4	..do ...	292	......	Slight boil around target in about 5 seconds.
300	5	32	30. 6	515	431	+ 84	Target rose slightly; a 6-foot jet from central hole.
301	5	20	18. 9	1, 015	832	+ 183	Smart shock, throwing iron wedges up and checking wood.
302	10	100	98. 2	Off scale	136	......	No upflow of water.
303	10	80	78. 2	..do ...	186	......	Bubbles rose in about a minute near target.
304	10	70	68. 2	..do ...	225	......	A small upflow under target.
305	10	60	58. 3	..do ...	280	......	Slight boil under target, raising one side a little.
306	10	50	48. 4	..do ...	363	......	Loose iron jingled—side of target raised a few inches.
307	10	40	38. 4	477	499	— 22	Target lifted several inches.
308	10	30	28. 6	810	749	+ 61	Loose articles thrown about. Whole target raised bodily.
371	10	27	25. 7	752	867	— 115	Raised one end 3 feet, anchor ropes being slack.
372	10	22	20. 9	998	1, 155	— 157	Target buried in spray; heavy shock; large buoy thrown off.
374	10	17	16. 1	1, 322	1, 645	— 323	Log thrown 15 feet up. Target rose squarely under great jet, and shows beginning of crack and upward bulge.
377	10	12	11. 6	1, 930	2, 590	— 660	Target buried in 60-foot jet, and broken through middle on line of oak logs. Twelve spruce logs, each 12 by 12 inches, torn asunder. One oak log broken in two places, and others damaged. Destruction complete.
309	20	90	88. 2	Off scale	250	......	A bubbling upflow of water about a minute after firing.
310	20	70	68. 2	..do ...	357	......	A boiling around target in 20 seconds.
311	20	50	48. 4	657	576	+ 81	Target buried in a 3-foot dome of water.
312	20	40	38. 4	921	792	+ 129	Target buried in a 4-foot dome of water. Wedges loosened.
313	20	30	28. 6	1, 207	1, 165	+ 42	A 15-foot jet threw target on edge and nearly upset it.
373	20	27	25. 7	1, 254	1, 377	— 123	A 50-foot jet buried target and shook it severely, but broke nothing.
375	20	22	20. 9	1, 337	1, 834	— 497	Jet 114 feet high. Target bulged and some gauge-seats split.
376	20	17	16. 1	2, 163	2, 611	— 448	Jet 45 feet high and of equal radius. Crack enlarging in top of target. Several gauge-seats shattered. Target weakened.
314	100	60	58. 3	1, 324	1, 300	+ 24	Jet 25 feet high rising under target turned it over. Bottom slightly splintered and several bolts gone.

A careful examination of this table will show that no material damage was done to the target before it was held down by anchors to receive the blow. This plan was tried for the first time in shot No. 371. It received seven blows when thus secured; and although some yielding was still possible, no large amount of work was lost from that cause before the last four shots were fired. In them the difference between the observed and computed pressure begins to be large enough to indicate a sensible reduction in the shock by reason of the motion. The target, although somewhat shaken by the rough handling it had received, did not show signs of serious weakening before the first of these four shots (No. 374, which opened the crack upon which it finally broke). Hence, its destruction may probably be attributed to them alone;

i. e., to the destructive effect of four successive instantaneous mean pressures of 1,322, 1,337, 2,163, and 1,930 pounds per square inch. What single blow would be the equivalent of these four can hardly be determined, but it would probably be considerably less than their sum (6,752 pounds), say 5,0 0 pounds per square inch delivered when the target was held rigidly in position. Such a blow would be received from a charge of 10 pounds at 6.5 feet, or of 100 pounds at 19.6 feet.

The trials with the iron target are more easily analyzed; since, after each sinking, it was thoroughly repaired and made as strong as at first.

The project for these trials contemplated several successive shots, each more damaging than any preceding it, to be continued until a fatal blow was given to the target.

The experiments began in June, 1875. Three shots were fired, Nos 388, 389, and 390, when the target sunk for the first time. It was raised and repaired, and five more shots were exploded near it, Nos. 391, 392, 393, 394, and 395, when it again sunk. This terminated the trials for that season. After a thorough restoration shot No. 428 was fired in August, 1876, again sinking it. Once more it was put in perfect order, and on September 12, 1877, it received the final shock.

In all these trials, except the last, the target was moored in water about 40 feet deep, and was held down to the blow in the manner described on page 39. The last of these shots having snapped nine of the sixteen chain cables like pack thread, and the flotation being insufficient to support heavier metal, the target in the final experiment was moored in 30 feet of water without any steadying attachments, and the distance between the bottom and the torpedo was diminished so as roughly to allow for the loss by motion.

The sixteen gauges recorded with precision the *actual* destructive intensity of the several blows. The dynamite formula, equation (21), having been sufficiently tested to give entire confidence in its indications, enabled the corresponding intensity due to the charge when acting upon a body held rigidly to receive the shock to be *computed.* The difference between these two quantities measures the loss due to the general motion or yielding of the target from lack of weight.

To place this loss in the most intelligible form, the charge required to give the intensity of action actually measured by the gauges has also been computed by the formula for each shot. This computation has been accurately made, using the known values of D and ϑ *for each lead,* and then adopting the mean of the sixteen gauges, thus determined, as the true result to compare with the real charge. By this process the probable error of each determination can readily be computed, and is given in the following table. It will be noticed that there was but little loss from motion except for the two nearest charges, and that for them this loss was enormous.

The table exhibits the general results of the several experiments, full details being given in Appendix C. The effects of each shot upon the target are discussed in the text immediately following the table:

Summary of iron target experiments.

No. of shot.	Charge, dynamite No. 1.				Depth of water.	Mean distance. (D)	Pressure per square inch. (Average, 16 gauges.)		
	Point of suspension.	Sub. (S)	Weight. (C)	Effective weight.			Observed.	Computed.	Difference.
		Feet.	*Pounds.*	*Pounds.*	*Feet.*	*Feet.*	*Pounds.*	*Pounds.*	*Pounds.*
388	13 feet outside No. 15 angle ..	30	20	22.4 ± 2.03	42	38.8	773	739	+ 34
389	......do	30	40	33.8 ± 2.77	42	38.3	1,044	1,184	— 140
390	Central	32.5	30	35.3 ± 2.34	39	30.8	1,523	1,403	+ 119
391	5 feet outside No. 15 angle ...	32.8	50	58.0 ± 4.46	40	35.6	1,674	1,565	+ 109
392	8 feet outside No. 15 angle....	32.8	75	72.6 ± 4.61	40	37.0	1,851	1,923	— 72
393	8 feet outside No. 14 angle....	31.8	100	110.3 ± 5.82	40	36.9	2,461	2,337	+ 124
394	Edge between Nos. 10 and 11.	30	100	87.5 ± 8.96	40	29.8	2,876	3,242	— 366
395	Edge between Nos. 6 and 7...	20	100	58.9 ± 6.41	40	20.9	3,540	5,305	— 1,765
428	Central	32.8	200	178.5 ± 5.58	42	30.8	4,596	4,956	— 360
478	Central	13	200	45.8 ± 2.08	30	12.1	6,523	17,836	—11,313

Shot No. 388.—Charge slung from a boom guyed from a small jury mast 24 feet high. The explosion was sharp and ringing, raising a jet of water 25 feet high, which lifted but did not break the boom. The target rolled considerably in the waves, but was not injured.

Shot No. 389.—Charge slung as before, and boom not broken, although thrown violently around. The target was buried in spray, the jet rising higher than the mast. The chain cables rattled, and a large stone was thrown upon the deck.

Shot No. 390.—Loud ring from the target, which rose squarely about a foot in a fine mist, settled back say 9 inches, and then rose again say 6 inches, when a jet burst upward through the central hole to a height of about 15 feet. The deck showed a slight upward bulging, with three small cracks, and a leak was opened in the bottom which caused the target to sink in about two hours. It settled down gently, turning over upon one side, and rested vertically on the mud.

A survey of the bottom of the target made after this shot is shown by Plate XVI. The figures near the gauge holes denote the registered pressures per square inch. The centre strake of the plating was cracked through seven rivet holes, and the adjacent butts were opened about a quarter of an inch (maximum). Contours refer to plane of bottom, and are 0.4 of an inch apart.

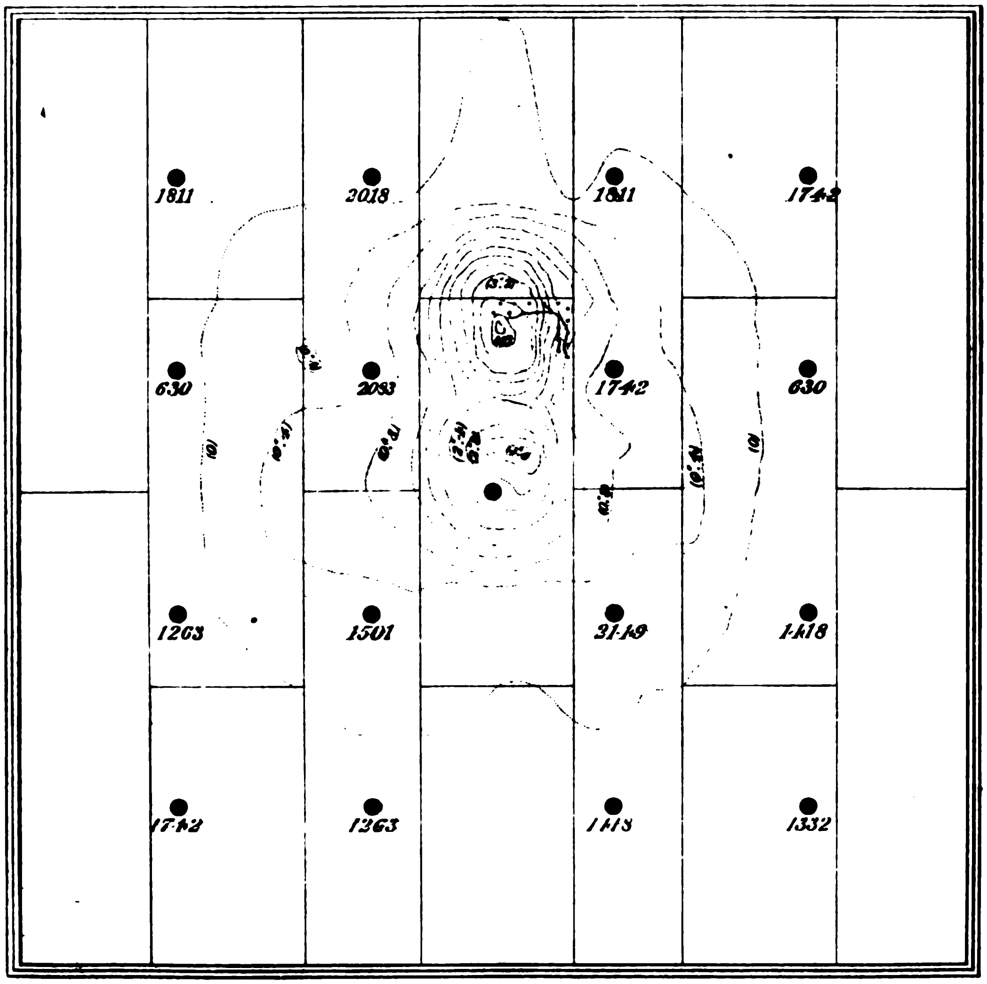
Shot No. 391.—A clear white jet, say 25 feet high, rose close alongside of the target, which rolled gently in the waves caused by the explosion. No damage. A fish was thrown on deck.

Shot No. 392.—A jet discolored by mud rose very close to the target, throwing mud and stones on deck. No injury could be detected by a careful inside inspection. The rolling, as before, was gentle.

BOTTOM OF IRON TARGET,
SHOWING EFFECT OF
30 LBS. OF DYNAMITE, FIRED 30 FT.
CENTRALLY UNDER IT.

NOTES.

Contours refer to original plane of bottom, and are drawn 0.4 inches apart. Figures at gauge holes indicate the registered mean pressure per square inch.



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Shot No. 393.—This shot was more serious than any of the preceding. The jet rose under the corner, bulging in that compartment about half an inch, and caused a very slight leak. Much mud fell on deck. A ⅞-inch bolt head was forced off from a deck plate near the manhole. The jet was high and a little deflected by the target, which plunged in the subsequent waves, but met the blow fairly.

Shot No. 394.—The jet (photographed) was 140 feet high and tinged with mud. The shock bulged the side plates from ¼ to ¾ inches on the side attacked, and opened some small leaks next bottom plate. The deck indicated a slight bulging upward, near the middle of the target. The rocking in the waves was violent.

Shot No. 395.—The jet (photographed) was 200 feet high. The chains, notwithstanding the heavy strain on them, were thrown about on deck, and the wedges holding down the gauge rods were loosened. Several small leaks were opened, which sunk the target in an hour and three-quarters in spite of the pumps. The chains scored the edges of the deck under the violent plunging of the target.

A survey of the bottom showed every compartment to be so bulged in as to distinctly reveal the fore and aft and athwartship framing; the average maximum depression for the twenty-five compartments was 1.5 inches, ranging from 0.8 inches to 2 2 inches. A long crack extended along the edge of the internal angle iron from No. 14 corner to within 5 feet of No. 13 corner.

Shot No. 428.—The jet (Plate XVII) rose to a height of 110 feet, and showed by a forked depression in the centre that its form was modified by striking the target. Of the sixteen ⅞-inch chain cables, seven were snapped and two others were let go, one by the breaking of a shackle and the other by the yielding of the anchor ring. Corner 16, with both its adjacent sides, was thus left free; indeed, only one complete connection from anchor to anchor remained over the target, and this was parallel to and next the side 14–13. With a telescope on shore the target was distinctly seen to rise, say 2 or 3 feet, before being enveloped by the jet. The vibration of the earth was noticed at a distance of 5 miles with a mercury seismometer, the shock arriving in about 5 seconds, while the jet was still high in the air. The target sunk in thirty minutes from injuries received.

The survey, after raising, showed so much general disorganization that, although there was no open rent, the question of repairs was a doubtful one. The bottom angle irons were broken and rivets sheared along all the four sides, and along about half of the bulkhead frames. Every bottom strake of plating showed cracks, some longitudinal and some transverse, the length ranging from a few inches to 4 feet; the inward bulging of more than half of the compartments exceeded 2 inches; the corner straps were all loosened; many bolt heads were gone; and, in a word, the structure was severely shaken, showing a tendency toward a dish-like form with the concavity downward. It was, however, finally decided to repair it for another trial.

Shot No. 478.—For this experiment no attempt was made to increase the stability of the target by anchorage, as the strain to be delivered was so great that nothing of the kind could be made to hold.

The shock was tremendous, instantly enveloping the target in a broad burst of water, which rose to a height of 75 feet (Plate XVIII). The four corners, being held by slack hemp cables to ship's anchors, prevented the overturning which had happened to the wooden target under like circumstances. When the water subsided the structure was seen laboring in a great vortex, which sent breakers to the beach a hundred yards distant; but it sunk in a few seconds before the upward boiling had ceased. One corner rested in the mud, thus leaving the plane of the bottom vertical and subjecting the gauges to no pressure from the weight.

The survey after the target was raised indicated plainly that its injuries were irreparable. The condition of the bottom is so well exhibited by Plate XIX that it is only needful to draw attention to the general breaks along the lines of rivets, and to the evidences of extra support afforded by the tubes for the gauges, and especially by the tube in the middle compartment used for slinging the torpedo. These most efficient braces form no part of the bottom of a ship-of-war; and if they had been absent there can be little doubt that the whole bottom of the target would have been disrupted.

The following figures represent the maximum inward bulging of the several compartments, beginning at the upper left hand corner and reading as from a book. The positions of the internal frames are so clearly marked on the plate that no further guide is necessary. The depressions are expressed in inches, reckoned from the primitive plane of the bottom.

4.5	4.3	6.0	4.3	4.1
5.8	7.0	Disrupted.	6.9	5.4
4.3	6.8	1.3	7.6	4.6
6.8	7.0	Disrupted.	6.5	5.4
4.3	3.8	6.1	4.1	4.8

The upper edge showed a general warping of 0.5 inches, the bottom edge of 0.7 inches, the right hand edge of 0.5 inches, and the left hand edge of 0.8 inches. Upon the lines of the internal framing this effect was still more marked, giving a slightly dished form to the whole bottom of the target.

As might be inferred from the plate, the inside exhibited an appearance not easy to describe. Angle irons were buckled and broken, rivets were generally sheared or had lost their heads, frames were bent and twisted, and, in one word, it was evident that the limit of endurance had been so nearly reached that either a small increase of force or a small reduction in strength, such, for example, as the removal of the gauge pipes, would have caused the total destruction of the target.

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[illegible] experiment no attempt was made to [illegible] the strain to be delivered was so great that [illegible] [illegible]

[illegible] instantly enveloping the target in a [illegible] [illegible] height of 75 feet (Plate XVIII). The four corners, being [illegible] ship's anchors, prevented the overturning which [illegible] [illegible] under like circumstances. When the water subsided [illegible] in a great vortex, which sent breakers to the [illegible] [illegible] it sank in a few seconds before the upward [illegible] [illegible] in the mud, thus leaving the plane of the bottom [illegible] [illegible] to no pressure from the weight.

[illegible] the target was raised indicated plainly that its injuries [illegible] [illegible] of the bottom is so well exhibited by Plate XIX [illegible] [illegible] attention to the general breaks along the lines of rivets, [illegible] support afforded by the tubes for the gauges, and especially [illegible] compartment used for slinging the torpedo. These [illegible] part of the bottom of a ship-of war; and if they had [illegible] no doubt that the whole bottom of the target would have [illegible]

[illegible] figures represent the maximum inward bulging of the [illegible] beginning at the upper left hand corner and reading as [illegible] internal frames are so clearly marked on the plate that [illegible] [illegible] depressions are expressed in inches, reckoned from [illegible] of the bottom.

1.7	4.3	6.0	4.3	1.1
5.[illegible]	7.0	Disrupted.	6.9	5.4
[illegible].3	6.8	1.3	7.6	4.6
6.8	7.0	Disrupted.	6.5	5.4
4.3	3.8	6.1	4.1	4.8

The upper edge showed a general warping of 0.5 inches, the bottom edge of [illegible] inches, the right hand edge of 0.5 inches, and the left hand edge of 0.8 inches. [illegible] the lines of [illegible] internal framing this effect was still more marked, giving a [illegible] dished form to the whole bottom of the target.

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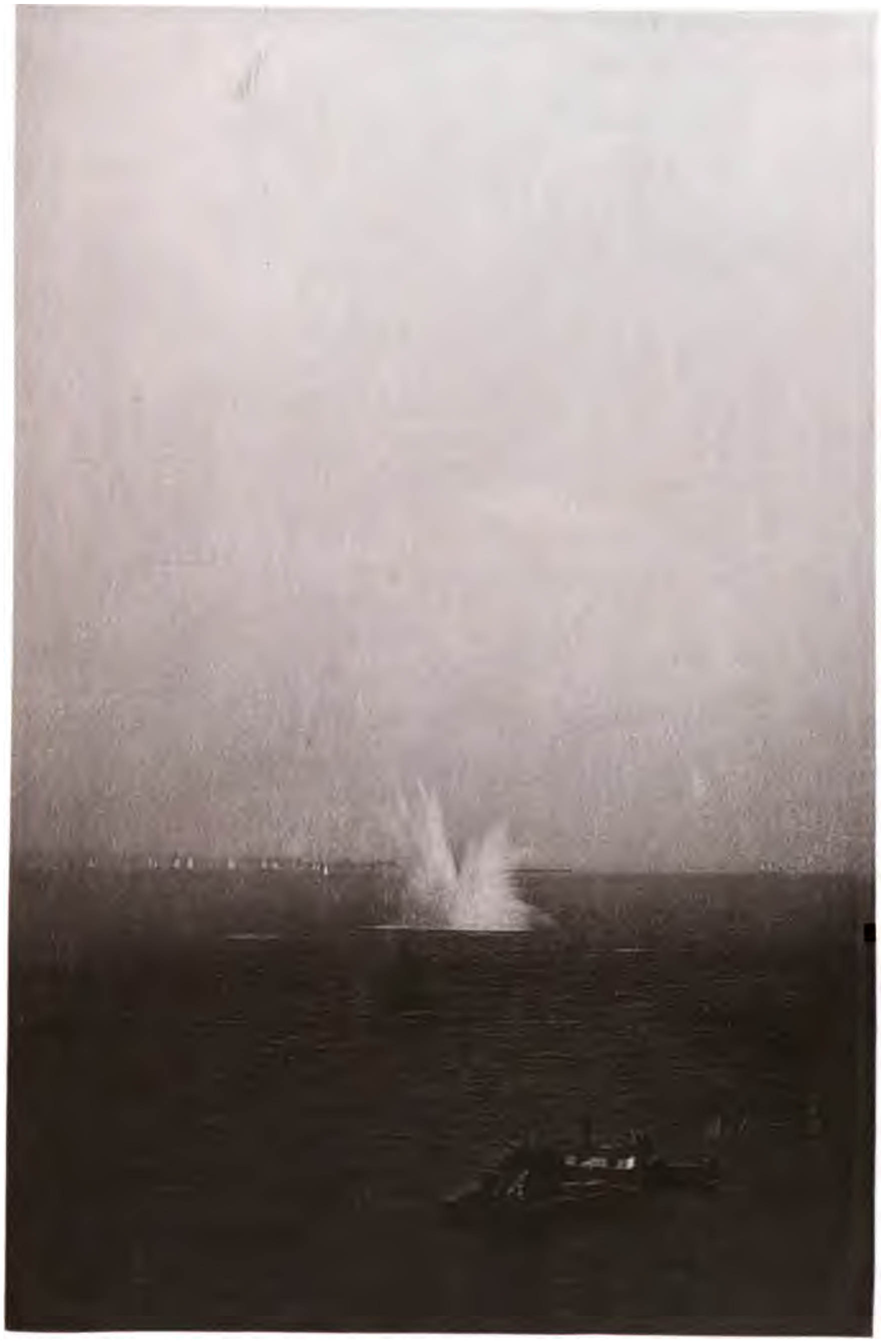

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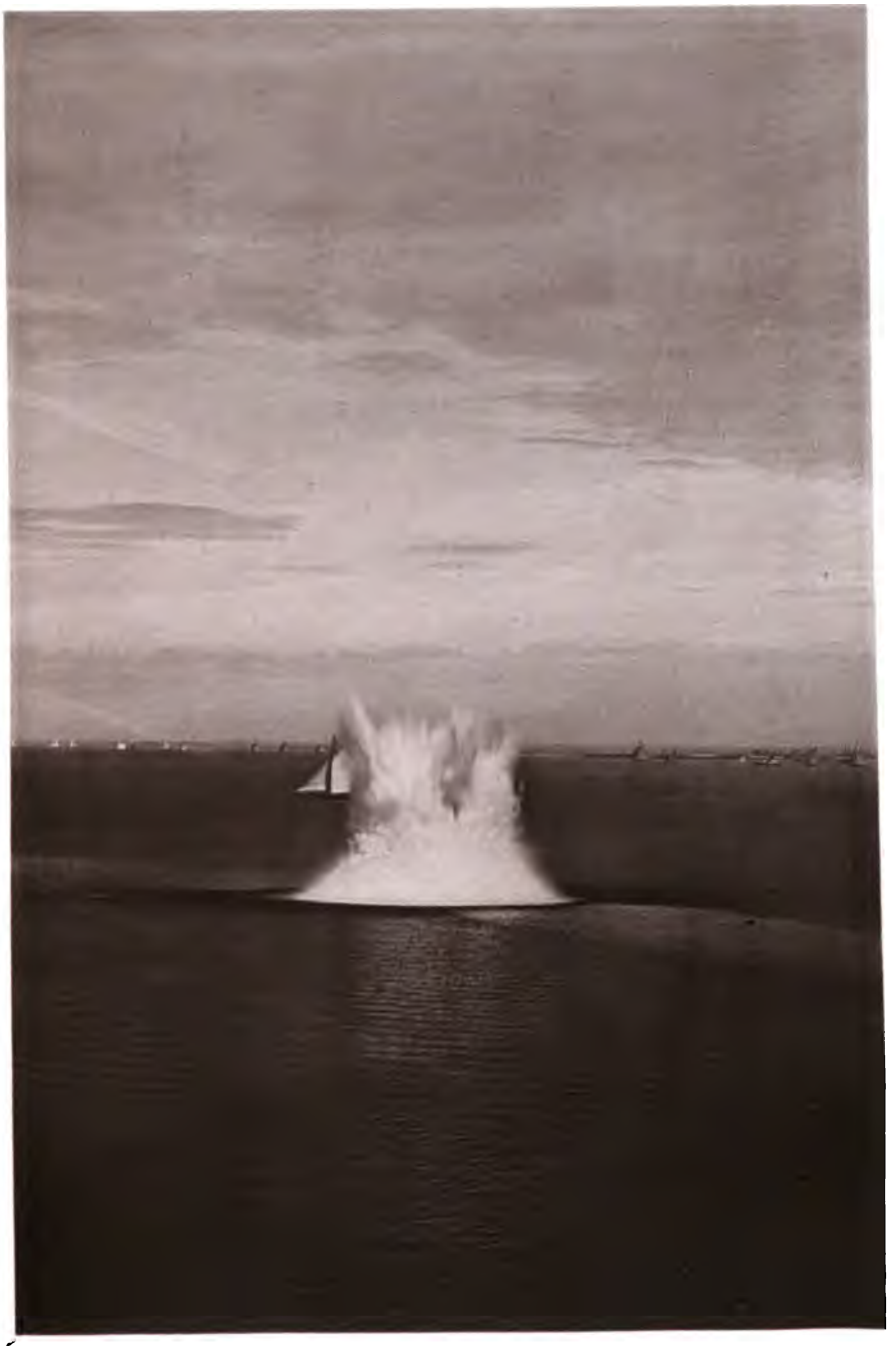

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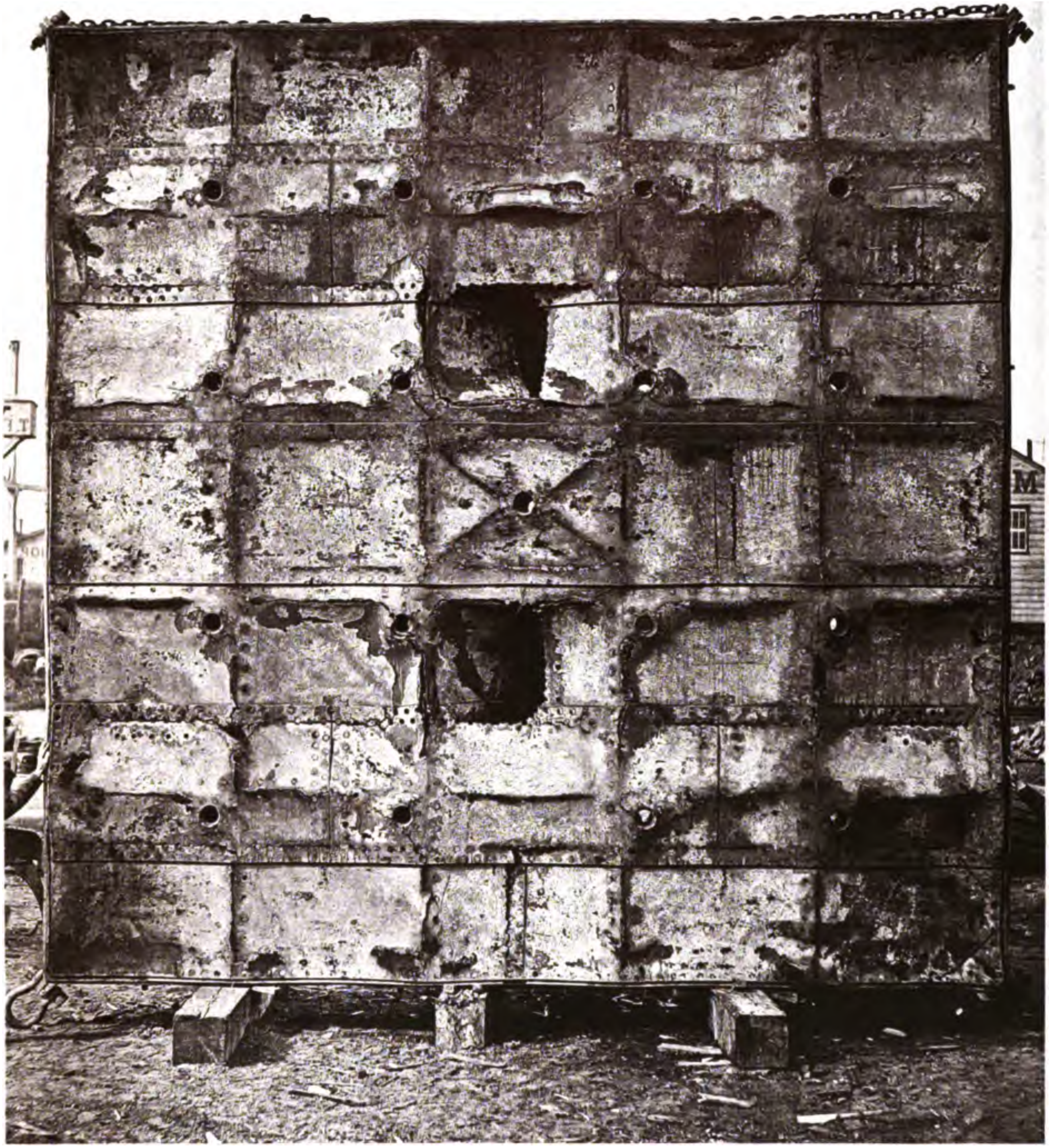

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The deck was cracked in several places, and forced into a slightly concave form corresponding to the bottom; so that, although no hole was broken, it was apparent that here also the limit of strength was nearly reached.

It remains to consider the intensity of the strains, exhibited by the last table, which had produced these several effects.

The remarkable accordance between the computed and the observed mean pressures for the first six shots shows that no serious loss occurred in consequence of the general motion; *i. e.*, that the system of anchorage had served its purpose perfectly.

When a charge of 100 pounds was placed *under the edge* of the target, even at the considerable distance of 30 feet, the loss becomes apparent; and when this range was reduced to 20 feet, not less than 30 per cent. of the whole intensity of the blow was absorbed in the recoil, notwithstanding the heavy chain anchorage.

When a charge of 200 pounds was placed 30 feet centrally under the target, thus developing the resisting power of the whole sixteen anchors, instead of one-half of them, as before, the loss was reduced to about 7 per cent.; but even this fraction was sufficient to snap every mooring except one. Remembering that these moorings consisted of ⅞-inch chain cables, attached at each end to a 1,000-pound anchor buried in mud, and strained by a strong tidal lift, the enormous force thus diverted from rupturing the target is evident.

In the last shot, when no anchorage was attempted, 200 pounds, placed centrally 10 feet under the target, expended 64 per cent of its developed intensity of action in giving motion, and only 36 per cent. in effecting rupture; thus exhibiting the immense advantage, to the defence, of the great weight of modern ships-of-war.

The actual destructive strains upon the target, of course, are measured by the registered and not by the computed mean pressures. Hence, it appears that when this quantity equals about 1,500 pounds per square inch, the blow will buckle the outer plating and be decidedly injurious to the ship, although not seriously damaging; when it equals 3,500 pounds, the shock will be severe upon the engines, movable articles, etc., but will cause no dangerous leak; and finally, when it equals 6,500 pounds, a large hole and a bad leak will be produced. This will be much worse than that caused in the target, because the effective stiffening due to the gauge pipes will be wanting, and also because the quality of iron in the structure was greatly superior to that used in ordinary ship-building.

The Oberon Experiments.—In the years 1874–'76, a series of experiments was made by the Government of Great Britain to determine the destructive range of large submarine explosions, directed against a first-class modern ship-of-war constructed upon the double cellular principle. No official report of these trials has been made public; but the essential facts appeared at the time in the public prints in sufficient detail to render it possible, by the aid of the formulæ derived from our own investigations, to analyze

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the results, and to deduce from them valuable information. A brief account of the several experiments, compiled from the best available authorities, will first be given.

The Oberon, an old side-wheel steamer, with an iron hull, was adapted for the experiments. She was fitted with an outer skin of iron, composed of $\frac{13}{16}$-inch and $\frac{7}{8}$-inch plates, lapped and double riveted. Her inner skin (the original bottom) consisted of half-inch plates, single riveted and supported by angle iron transverse frames 21 inches apart. These frames were made of two pieces of angle iron riveted together. The distance between the inner and outer skins was 3.5 feet at the keel, and 2.25 feet above the water-line. The space between the two bottoms was divided into compartments by longitudinal and transverse frames—the latter 4 feet apart, the former supporting every alternate outer plate. In general, these frames were pierced by circular manholes; but every fourth transverse frame was solid, forming water-tight bulkheads. In fine, her sides were made about equal in strength to those of H. M. S. Hercules; and her hull was divided by bulkheads into seven water-tight compartments. In her was placed a condenser fitted with inlet and outlet valves, which were left open. She was also fitted with a Kingston feed pump valve, which was closed. The water-line was 2 inches above the top of the condenser. The weight of the hull, before the outer skin was fitted, was 590 tons; and the additions brought her weight up to 920 tons—the cables, condensers, etc., adding 30 tons more. The mean draft of the vessel was 11.3 feet.

These figures show that the Oberon by no means represented a modern armored ship in absolute weight, and hence in stability; and the probable reduction in her local injuries due to this cause was not overlooked in the public discussion of these experiments. Thus "Engineering," referring to a statement previously made in that journal to the effect that, had the Oberon been fully equipped with engines, boilers, armor-plating, armament, crew, and stores, she could not have failed to sustain, even from the first, serious if not fatal damage, continues: "The reason for this is that she would then present a static resistance of about 10,000, instead of, as she does, 1,000 tons. It is held by some that, in the case as put by us, the vessel would have a certain amount of way on, by which that distance would be somewhat reduced; and, moreover, that the Oberon is moored head and stern, which nearly compensates for the absence of her working weight. To this we must demur, seeing that the question of the vessel's motion depends entirely upon the direction of that motion. Were the direction one in which she was advancing towards the torpedo—as it probably would be—it would increase the effect of the blow upon her, whilst, were she passing the mine, her motion would barely reduce it, if at all; that is, if she were properly within reach of the mine. With regard to her moorings, although she may be held all taut, her two head and two stern mooring chains cannot give an equivalent to 9,000 tons of resistance. In other words, it would not require a force of 2,250 tons to draw each of these moorings. Therefore, we repeat that the Oberon is not a correct measure of resistance, nor are the results of the explosion of 500 pounds of gun-cotton against her an equivalent of the results of a similar explosion against a fully equipped vessel of the same size."

On the side next the torpedo were placed 44 crusher gauges, each exposing two-thirds of a square inch of piston area, and containing a cylinder made of lead hardened with antimony. These cylinders were half an inch long, and one-twelfth of a square inch in sectional area. Suspended by 3-inch ropes, over each side of the vessel, were six 18-pounder shot—each fitted with a crusher gauge having a piston of less weight, but in other respects similar to those just described. None of the records obtained by these gauges have been made public.

The mines each consisted of 500 pounds of compressed gun-cotton, saturated with 33 per cent. of fresh water, and placed in an iron case of the service pattern. The charges at first were primed with 9-ounce disks of dry compressed gun-cotton in waterproof bags; but these primings were subsequently increased. They were fired by two detonating fuzes (No. 6 Abel, submarine), connected in divided circuit and ignited by an electric battery.

First experiment.—Fired August 6, 1874. The charge was placed on the bottom in 48 feet of water, on the starboard broadside of the Oberon, at a horizontal distance of 100 feet from the vessel, which was moored in 60 feet of water. No harm was done to the hull, but the condenser pipe of the engines was split, an injury which would interfere with the ship's capacity for sailing at full speed.

Second experiment.—The second shot was fired on August 21, 1874, under conditions similar to the first, except that the charge was placed 20 feet nearer the Oberon, or 80 feet distant. The vessel lay at her former moorings. An external examination of the hull disclosed no appearance of damage. The water-ballast tanks in the after-hold were removed from their original position, and three of the 4-inch timber struts which had served to hold them in place were forced from their bearings, one being broken. The ballast tanks in the forward hold were not disturbed, although the ladder and other light objects were moved about 8 inches from the side of the vessel exposed to the force of the explosion. The same disturbance was also observable on deck, where dead-eyes were found to have been started from their sockets, the seams of the deck slightly opened, and loose gratings and covers displaced to a like extent as the articles on the lower decks. That her steaming power would have been impaired appeared more certain than in the previous experiment, but an examination in the dry dock disclosed no signs of injury to the plates of the hull.

Third experiment.—This shot was fired on September 5, 1874, and the experiment was conducted under precisely similar conditions to those which had preceded it, except that the distance between the torpedo and the vessel was reduced to 60 feet.

An internal examination of the vessel after the explosion disclosed the fact that the hatchway coaming had become unshipped, and the tanks displaced as before. An examination of her bottom after she had been docked showed, although no appreciable damage had been done to it, that the limits of safety were being approached. As in the second trial, sheep and rabbits placed on board escaped uninjured.

Fourth experiment.—Fired on September 26, 1874. The distance of the torpedo from the vessel was decreased to 50 feet, the other conditions being the same as in former experiments.

To insure the floating of the Oberon after the explosion, until she could be towed into dock, a large quantity of iron ballast was taken out, and water tanks and casks were stowed in her. Most of these were empty, but some of them were filled with water to supply the weight required to bring the vessel down to her proper draft. Heavy balks of timber were set up between the paddle-box outer beams and the upper edge of the outer bottom, clear of her sides, in order to afford a hold for the lifting chains. The chain cables provided for holding her together in the event of her hull being fractured by the mine, or for enabling her to be raised, were disposed in four double loops extending over each side and around the bottom of the vessel. She had also a double length of chains placed in line with her keel, connected with the transverse loops and made fast inboard over each bow and quarter. Other precautionary measures were taken to keep the vessel clear of water should a breach be effected, or to raise her in case she should be sunk.

The effect of this explosion upon the Oberon was impressive. The outer mass of the upheaved water striking her on the starboard side caused her to rise up to a height several feet above the level of the surrounding water, and fall again into the midst of the swell surging up on the crater's edge. She rolled heavily for some minutes, and had the appearance of being about to settle down.

She was quickly boarded, and the expedients for keeping her afloat were applied, but before reaching the dock, it was found that the only water she contained was that which had been shipped from the column thrown up by the explosion.

An external examination made in the dock disclosed a very marked impression on her outer skin. The pressure brought upon the plating had buckled it to a considerable extent, so that the longitudinal and vertical framing between the inner and outer skins stood out in bold relief. The enormous and instantaneous pressure given by the explosion to the sides of the double bottom nearest the mine was found to have driven in the outer plating between the frames, the vertical frames exhibiting this feature more than the horizontal. A series of flat arches, thus formed, told what might have happened had the forces spent in doing this found only a small opening for an entrance. The weakest part of the Oberon's bottom was near the great inlet pipe, with its grated cover, leading from one of the lower strakes of plating to the

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condenser, weakened also by the outlet pipe some feet above it in another strake of plating. Here a rivet was found to have been so nearly driven out that it was removed and replaced with a wooden plug. All the rivets for many feet round were started; the outlet pipe from the condenser (of iron and about 12 inches in diameter) was split longitudinally between the outer and inner iron skins of the double bottom; indeed, all the flanges of the condenser's sea connections were damaged. The vessel's floating power, however, was not affected.

Fifth experiment.—The fifth of the series of experiments against the Oberon was set down for November 10, 1874. The signal "all ready" to the firing party on shore at Fort Monckton was answered by a closing of the electrical circuit, which, however, only had the effect of exploding the priming charge of dry gun-cotton discs. A slight upheaval of water and a small burst of spray made known the fact that the primer had failed to explode the main charge.

The general opinion at the time was that the main charge of gun-cotton had been super-saturated with water, and had therefore failed to answer to the explosion of the priming charge of dry discs. Against this there is the fact that charges of gun-cotton saturated with the proper percentage of water have been further immersed for a considerable period and yet exploded by dry discs.

It was stated by some critical observers near the Oberon that a puff of smoke was emitted from the disturbed water over the torpedo. If this were really so it would indicate the ignition of the main charge, and its imperfect combustion until stopped by the rush of water into the ruptured iron case. All that was recovered of the torpedo by the Royal Engineers was the wire rope by which it had been suspended, and the two iron straps with which it had been bound. The shell containing crusher gauges remained attached to the rope, with the 5 cwt. mooring-anchor; and the divers also succeeded in securing portions of the main charge.

The hypothesis framed upon these data by the committee was that the wet charge had not exploded from want of proper contact with the primer of dry discs, but that the explosion of the primer was sufficient to blow the iron case open. The question was also raised whether a priming charge of 1 pound was large enough.*

On November 12, 1874, the experiment was successfully made under conditions similar to those of the previous trials, except that the priming charge of dry gun-cotton was increased to 2 pounds, and the torpedo, instead of being placed on the bottom, was suspended in the water from a spar projected 30 feet from the port (uninjured) side of the Oberon, in a line with her deck. The vessel was drawing 12 feet of water;

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* With 4-pound charges of granulated gun-cotton, soaked by 1 pound of fresh water and primed with 0.75 ounces of dry disc gun-cotton, and with 2-pound charges of disc gun-cotton, containing 28 per cent. of fresh water and primed with 1.75 ounces of dry disc gun-cotton, miss fires similar to this have occurred more than once at Willets Point. (See Appendix A.) Similar failures have also been noted in the experiments at Hallett's Point and Flood Rock, New York Harbor.

so that the absolute distance of the charge from the hull was 52 feet, the charge being submerged 48 feet in about 66 feet of water.

When the water from the outburst of the explosion struck the vessel she rose and careened slightly. The height of the jet of water was estimated at over 250 feet. Upon docking her, and pumping her clear of the water which she had shipped from the upheaved mass, it was found that no leak was sprung. The extent of the damage to the outer skin was slight, although it extended over the whole immersed surface of the ship's exposed side from the bow to the ninth vertical frame (a length of about 35 or 40 feet), and from the keel to the water-line. The plates were bent in, say three-fourths of an inch at the utmost, from their proper outline between the frames; but otherwise there was neither opening of the seams nor of the caulking. On board there was less disturbance than on some previous occasions. All the movable objects were displaced in the fore compartments, but the extent of the injuries rapidly diminished toward the after part of the ship, the mine having been exploded well forward.

The detailed effects of this explosion on board the Oberon were:

Compartment 1 (bow)—On starboard side of lower deck second knee started so that a chisel blade could be inserted between it and the under side of the deck; ladder thrown down; one iron midship stanchion loosened; 1-inch bolthead off from second port knee, and another bolt loosened. Below this deck the second beam was slightly sprung, and from the third beam there were half a dozen boltheads off.

Compartment 2.—In space below the lower deck there was one ½-inch bolthead off from port side of centre of first deck beam; one off from second beam on starboard half; top barrels, filled with water, were slightly shifted. On the lower deck the ventilator covers were displaced on starboard side, being jerked to port nearly a yard; the strut to fourth beam on starboard side was shifted ¼ inch. On deck the cable bit arm, a piece of timber 12 by 20 inches in section and 10 feet long, was moved 6 inches away from the bit to its port end.

Compartment 3.—On lower deck everything movable was violently displaced; the sheep were thrown down; the iron water-tanks were displaced; two of the 4-inch struts in starboard portion of the cabin were forced upwards so as to start the deck-planks above them; one strut was broken and left lying on starboard side of lower deck; at 6 feet abaft the foremost bulkhead the iron covering or outside ledge of the double bottom was separated $\frac{1}{16}$ inch over a short distance. A timber strut, 8 by 10 inches, stretching from foremost bulkhead to third beam, was started 4 inches; the foremost iron stanchion, 2½ inches in diameter, was thrown down; the struts generally were displaced, as also the iron water-tanks and all movable objects; and lastly, the great transverse wood beam above the aftermost bulkhead was lifted vertically, showing a long crevice in some places ¾ inches wide. Of the 1¼-inch mooring chain cable, two bights, one about 6 feet and the other 10 feet, were thrown down the hatchway.

This massive chain must have been jerked upwards at least 3 inches. On deck the spar which suspended the torpedo had been broken off at 6 feet from the ship's side, and the portion remaining overboard had a split 10 feet long from the broken end. The 2-inch wire rope shackle, or ⅝-inch iron ring, which had been attached to the torpedo showed the wire rope frayed for about 4 feet, and having 3 out of 6 strands cut at the joint with the shackle.

Compartment 4.—One iron water-tank was displaced, and several of the covers were thrown off; two struts thrown down; engine-room hatch on starboard side thrown 1 foot aside after a vertical lift of at least 3 inches. All the remaining struts shifted.

Compartment 5.—The after-pipe from inlet valve of condenser was leaking a good deal at the top side of the joint of the flanges next the condenser; from these flanges there were four boltheads broken off. The valve had been left open during the explosion; the exit valve had been closed, and there was no injury done to the exit pipe.

The condenser had filled while the Oberon was at her moorings, showing that the inlet valve had leaked; but after the explosion water was not to be found at the top of the condenser with the valves shut down. Hence it follows that the leak at the flanges was enough to exceed the leaks of the valves, and to gradually empty the condenser. All the shores to the iron ballast tanks were slightly shifted, and the lids of the tanks were displaced.

Compartment 6.—The wedges on deck (above this compartment) at the foot of the derrick were slightly shifted; below, nothing was amiss.

Compartment 7.—No damage.

Compartment 8.—A wood stanchion was thrown down and broken along the line of the previous split.

The crusher gauge, suspended over the ship's side, at 15 feet depth, gave the highest pressure yet obtained.

Sixth experiment.—Fired on November 28, 1874. The mine was charged, as before, with 500 pounds of disc gun-cotton (wetted by 30 per cent. of water), and was placed on a shoal at 30 feet distance from the stern of the Oberon, on the starboard quarter; submergence, 48 feet; horizontal distance from outer skin of double bottom, 30 feet. The actual distance was 52 feet, as in the fifth shot, the object being to ascertain the difference between the effects of a buoyant and a ground mine under similar conditions of charge and distance. The observed effect of the blow was that the vessel lifted considerably by the stern and careened over to the port side, falling again into the trough of the sea, her bow remaining practically stationary.

When docked, it was seen that the outside of the double bottom had suffered more than in the last experiment, and that the damage was confined within a smaller

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area. Some of the plates of the outer skin between the longitudinals were bent inwards and a little cracked in the line of rivets; and the thin unsupported plate connecting the two sides of the double bottom abaft the stern post was broken so as to admit water—the fracture being evidently due to the blow from the explosion taking effect on the edge of the plate. A large amount of displacement occurred with the tanks and movables in the compartments nearest the stern and exposed to the full shock of the explosion—the displacement decreasing with the distance from the stern. The joints of the condenser inlet pipe in the engine room were again started and were leaking considerably. On deck, the heavy framing forming the anchor bit was dismantled; two small fire engines, placed on board for pumping, were thrown considerably out of position, and all movables were displaced. It was said by some that three large objects were thrown 10 feet into the air—probably the two engines and anchor bit frames.

Some of the plates of the outer skin in the direct line of the explosion were much buckled, and showed signs of fracture along some of the lines of the rivets.

The inner skin of the double bottom was still intact. No water got inside the ship, and when she entered the dock her trim was altered by 16 inches greater depth in stern and 10 inches less by head, showing that but little water got into the double bottom by way of the fracture.

The general opinion was that this ground mine had delivered a more direct and concentrated blow upon the bottom of the ship, and had done greater damage than the similar buoyant one in the fifth experiment.

Seventh experiment.—Fired on May 20, 1875. The charge, 500 pounds damp gun-cotton as before, was placed opposite No. 18 transverse frame on the starboard side, and vertically under the upper edge of the double bottom. The torpedo was lowered to the bottom in 48 feet of water, the absolute distance from the nearest point of the outer skin being 38.5 feet. Immediately after the explosion there were two distinct upheavals of water, the first clear, the second black. The ship sprang from the water and canted to the starboard. The foremast fell, the bridge disappeared, the coamings and movable gear flew about the deck in all directions. A tug-boat took her in tow, but she filled so fast that it was necessary to run her on a shoal. It was found, on examination, that the Oberon had made 14 or 15 feet of water, and that the effects of the explosion were disastrous. On the starboard side, almost amidships, there was a gaping rent; and there was also a large hole in the port side, in the vicinity of the water-tight bulkhead.

Commander Sleeman gives the following additional details:

"*Effect of explosion.*—Outer and inner bottom broken entirely asunder at No. 19 frame on the starboard side, and between Nos. 16 and 17 on the port side. A fracture was caused in the outer bottom extending from the shelf plate to upper edge of strake next the keel on the starboard side, and from the shelf plate to upper edge of flat keel plate on the port side. A fracture was also caused in the inner skin extending from the topside to the outer edge of the garboard strake on the starboard side, and from the topside to upper edge of garboard strake on the port side; this including a fracture of the keel at No. 17. The vertical keel, the longitudinals, as well as numerous bracket plates and angle irons, were broken, and about 2,000 rivets in the outer bottom were rendered defective.

"The outer bottom was indented over a considerable length, the indentation being greatest between the frames, and the maximum being 8 inches. The inner bottom was not indented or damaged, with the exception of the fractures before mentioned."

This terminated the series of experiments conducted by the Royal Engineers; and the Torpedo Commission took her in charge.

Eighth experiment.—All the injuries which the Oberon had sustained had been repaired; the fore and aft compartments were filled with empty casks to supply flotation; her bulkheads had been so tightened and renovated that she was found to be perfectly water-tight, and well calculated to oppose a fair amount of resistance to the charges which were to be fired against her. Her lower plating remained the same as before.

The vessel was moored fore and aft at the extreme reach of Portsmouth Creek. It was nearly high-tide when the mines were fired, giving an actual depth of about 26 feet. The vessel drew about 11 feet.

Commander Sleeman (my only authority for this experiment, which for some reason was not reported in the journals), states the details as follows:

"Torpedo, 60 pounds of gun-cotton in slabs, saturated with water. Total weight of charge, 75 pounds. It was enclosed in a ¼-inch iron case with cast iron ends. It was placed at 15 feet actual distance from the nearest side of the case to the target, and opposite No. 4 frame on the port side, 10 feet below the surface of the water.

"Effect of the explosion.—The effect upon the vessel was unappreciable. This charge represented the large Whitehead fish torpedo, and its position corresponded to that of this torpedo when striking a net at a small angle with the keel."

Ninth experiment.—Fired on June 12, 1876. Three torpedoes were fired simultaneously by Captain Heneage, R. E., in continuous circuit, the vessel being moored in water 16 feet deep. They were as follows:

No. 9 *a.* A Harvey torpedo, containing 66 pounds of gunpowder primed with the service (laboratory) bolt. The case was filled with gunpowder, and was fired by means of a powder fuze, ignited electrically. It was exploded on the starboard bow, opposite No. 4 water-tight frame. The centre of the torpedo was 9¼ feet below the surface, and 3 feet from the nearest point of the vessel's side.

No. 9 *b.* A rectangular iron case, containing 33 pounds of slab gun-cotton (25 per cent. of water being added), was placed, when exploded, opposite No. 30½ frame on the port side; primer, a slab of dry gun-cotton 2¼ pounds in weight; fuze, an electric detonator; centre of charge, 4 feet from nearest point of vessel's side, and 9¼ feet below surface A service steam pinnace with steam up and fitted with torpedo gear, one pole being rigged out, was placed at a distance of 22 feet from the charge.

No. 9 *c.* Similar to No. 9 *b*, the charge being, however, 33 pounds of granulated gun-cotton (25 per cent. water added) placed on the starboard side opposite No. 30½ frame. The primer was a disc of dry gun-cotton, 2 pounds 10 ounces in weight. A service steam launch, with steam up and fitted with torpedo gear, one pole being rigged out, was placed at a distance of 22 feet from the charge.

One purpose of this experiment was to test the effect of offensive torpedoes, such as would be adopted in an engagement; and to verify the results of the Norwegians and Danes, and more particularly of the Swedes at Carlscrona, with reference to firing comparatively light charges in actual contact. There were also two other purposes to be served by the experiments; viz, to ascertain whether gun-cotton would prove as effective for the purpose in view as dynamite, the explosive used at Carlscrona; and furthermore, to test the relative values of gun-cotton slabs manufactured at the Waltham Abbey Works, and the granulated gun-cotton made at Prentice's, Stowmarket. The density of the former is exactly double that of the latter, so that the cylinder used in the No. 9 *c* experiment required to be twice the size of that in No. 9 *b*. Each slab weighs 2½ pounds, and measures 6 inches square. The charges were suspended from the sides of the ship by warps passing through eyes, and were kept at the requisite distance from the hull by wooden stays.

The effect of the explosion was not so startling, nor was the result of the experiment so evident at the outset, as on last year. So far as the action of the Harvey torpedo manifested itself to the eye, the effect was insignificant; but as the smoke of the discharge found its way up, it seemed that the shock had either loosened some of the bolts or had perforated some of the plating. With respect to the effect of the two preparations of gun-cotton, there was soon no doubt; for although the Oberon remained for a few minutes apparently as buoyant as ever, she gradually went down by the stern, and would have sunk completely had there been sufficient water.

On the following day at low-water, when the Oberon lay high and dry on the beach, she was visited by the Torpedo Commission. It was only possible to make a cursory examination of her condition, but it was readily perceived that she had been more injured by the explosion than was at first inferred from the deliberate way in which she settled. Every charge seemed to have told with effect, and the Oberon was apparently useless for further experiments.

Contrary to the first general impression, the Harvey torpedo inflicted extensive damage. That the effect was not evident at the time was no doubt due to the forward compartment being filled with casks, which tended to preserve the buoyancy of the ship. The charge, however, punched a ragged hole in the outward bottom on the starboard bow, about 3 feet broad at its greatest diameter, and extending from No. 2 to No. 6 frame, or a distance of 12 feet. From the armor-shelf downwards there were five sound plates, but the sixth strake was blown out and two others were bulged inwards.

After docking it appeared that this torpedo had split or bulged in the whole outer bottom for about 16 square feet, extending downwards through two longitudinals to the garboard plates, and laterally to the water-tight frame on each side of No. 4, utterly destroying the intermediate brackets. The injury here was very clearly defined, the longitudinals and frames having apparently acted as knives, so cleanly had the plates forced in upon them been cut through in the direction of the fibre of the iron. Had the longitudinal girders been placed closer together the resistance would have been greater and the damage to the inner bottom, at least, would have been less. The bracket-frames, which were only kept in position by angle irons, seemed to have been snapped and doubled up with alarming ease by the force of the concussion. The inner bottom was extensively damaged and bulged in, but not so much as might have been supposed from the appearance of the outer skin, the straightness of the bows having allowed much of the explosion to spend itself vertically.

But the greatest damage was inflicted near the No. 30½ frame, against which the two preparations of gun-cotton had taken effect. The rent here on both sides of the outer bottom extended longitudinally (in the direction of the fibre of the iron) about 18 feet, and from the third strake below the armor-shelf nearly to the keel-plating. There was also a crack throughout the whole section of the ship. The greatest force appeared to have been exerted by the granulated gun-cotton on the starboard side. The iron skin was torn from the rivets, the girders and bracket-frames were displaced, and the upper plating was wrenched completely from its supports and blown away. The port side of the same frame presented a similarly ruinous aspect. The only difference—and practically it is one without a distinction—was that the plates, instead of being broken off, were lacerated in all directions and forced upon the inner bottom, which here, as also on the opposite side, was torn and forced inwards. With the exception that the taffrail was blown away and the galley dismantled, the explosive forces seemed to have been confined for the most part within well-defined limits. The wounds left by the previous experiments were not re-opened; and though the ship must have been lifted fore and aft, the fissures amidships did not appear to have extended.

Of the seven water-tight compartments, the two nearest the torpedoes were the only ones filled with water. Four others were partly filled by leakages through the intervening bulkheads, not, however, caused by injurious concussion. The centre compartment, occupied by the machinery, was perfectly dry; in consequence of which, and of the buoyancy afforded fore and aft by the casks, the vessel floated at high-water on the day after the experiment.

The steam launches did not suffer in the least from the combined explosions. This was an important part of the experiment, since the launches were in the positions that they would have occupied in ramming an enemy. One hundred and twenty pounds of gunpowder have been exploded, without injury, from the spar of a torpedo boat in the open sea, but never before close alongside a large ship.

Discussion of the Oberon experiments.—Having discovered by our own investigations the formulæ representing the laws governing the action of the explosives employed against the Oberon, it has been easy to compute the mean instantaneous pressure exerted upon her by the several shots; and then, by studying her reported injuries in connection with these pressures, to determine what shock may be accepted as certainly destructive. Knowing this, the corresponding (and hence dangerous) range of dynamite, or of any other of our explosives, may readily be determined by its known formula. It is true that this method of analysis does not correct for the loss of destructive energy due to the excessive recoil of the Oberon by reason of her deficient weight, but any error thus caused in the estimate will be on the safe side.

Not knowing the exact curvature of the hull, the nearest point, *i. e.*, that receiving the heaviest shock, has been assumed to be 5 feet under the surface for the first, second, third, and fourth; 10 feet for the fifth and sixth; and 11 feet for the seventh experiment. The general formula for gun-cotton (equation 25) has been used for that explosive, and that for sporting power (equation 13) for the gunpowder torpedo. The following table exhibits the results of these computations:

Analysis of Oberon experiments.

No. of shot.	Explosive.		Distance. (D)	Angle from nadir. (ϑ)	Mean pressure per square inch. (P)	Remarks.
	Kind.	Weight. (C)				
		Pounds.	*Feet.*	°	*Pounds.*	
1	Disc gun-cotton, wet	500	109	113	1, 235	Condenser pipe split; no serious damage.
2	do	500	91	118	1, 609	Much shaken, but no rupture.
3	do	500	74	125	2, 196	Seriously shaken; no rupture of the bottom.
4	do	500	66	131	2, 612	Outer plating buckled; rivets started; no leak.
5	do	500	52	137	3, 697	Outer plates and bracing much buckled; greatly shaken; no leak.
6	do	500	52	137	3, 697	Greatly shaken; small leaks started, but no fatal rupture.
7	do	500	38. 5	164	5, 996	Fatal shock; much damage of various kinds; ship sunk.
8	Slab gun-cotton, wet	60	15	100	4, 927	Inappreciable (Sleeman).
9a	Gunpowder, sporting	66	3	100	4, 155	Fatal local shock; large hole opened.
9b	Slab gun-cotton, wet	33	4	100	19, 800	Do.
9c	Granulated gun-cotton, wet	33	4	100	19, 800	Do.

Without the detailed records of the gauges used in these trials it is impossible to decide how much the recoil of the ship reduced the intensity of action of the blows, as above computed; but this is the less to be regretted, since any error resulting from this cause will tend to increase the estimated power of resistance of the Oberon.

Another point merits attention. The above figures indicate the *maximum* intensity of action to which the ship would have been subjected had she been held rigidly to receive the shocks; but there is one important difference between the large and the small charges which does not fully appear. The effects of the latter are much *more local* than those of the former; in other words a great charge at a considerable distance delivers a blow which differs but little in intensity over a large surface of the ship's bottom; while a small charge in the close vicinity acts like a projectile, and occasions an intense local strain. To illustrate this, numerically, for the more severe of the shocks, the following figures are given exhibiting the mean pressures in pounds per square inch at different points upon a horizontal line of the hull. The distances are reckoned from the point nearest to the charge, at which, of course, the effect is at its maximum; and, to simplify the comparison, the line of action is supposed to be normal to the hull at that point.

	Shot No. 9 (*b* & *c*).	Shot No. 6.	Shot No. 7.
Mean pressure at nearest point	P = 19,800	3,697	5,996
Mean pressure at 5 feet from nearest point	P = 10,260	3,672	5,928
Mean pressure at 10 feet from nearest point	P = 4,957	3,603	5,719
Mean pressure at 15 feet from nearest point	P = 2,973	3,496	5,434
Mean pressure at 20 feet from nearest point	P = 2,346	3,356	5,074
Mean pressure at 25 feet from nearest point	P = 1,499	3,195	4,689

These figures place in a strong light one advantage of exploding a small charge near the ship. The blow is then delivered locally with intense violence, and its effect is not weakened by a general pressure tending to give motion to the hull, and thus to reduce the disruptive strain. On the other hand the racking effect which throws the engine out of gear, displaces and perhaps explodes the boilers, shakes up and demoralizes the crew, and, in one word, subjects the vessel to a generally destructive shock without perforating her bottom, is more severe with large charges at a distance than with small charges near the ship. The old problem of punching and racking, so much discussed in connection with armor-plating, thus comes up again under a new form in submarine mining.

The punching problem is the only one which can be closely analyzed for the Oberon, with the data at hand.

A study of the foregoing figures and of the corresponding report of injuries inflicted, with a small allowance for probable reduction of intensity of action due to the abnormal lightness of the ship, leads to the conclusion that an instantaneous mean pressure of 5,500 pounds per square inch exceeded the resisting power of the hull of the Oberon; and hence that such a blow would cripple the Hercules in action. The effect of the gunpowder torpedo would suggest a rather smaller numerical value for this standard; and it will be seen hereafter that in some other cases a like result is indicated. The explosion of a chemical mixture occasions a more sustained pressure than one of equal intensity from a chemical compound, and hence it may be true that different standards would be admissible in the two cases. This view has not been adopted because the action of gunpowder is so variable that a larger margin should be allowed.

Experiments at Carlscrona, Sweden.—Two important series of experiments have been conducted by the Swedish Government—one in 1868, and the other in 1874–'76. The following information concerning them is derived from the volume upon Torpedoes and Torpedo Warfare, published in 1880 by Commander C. W. Sleeman, late of the Imperial Ottoman Navy.

Of the first series he states:

"These experiments were made to investigate the effect of submarine contact mines, charged with dynamite, against a strong wooden vessel, as well as against a double-bottomed iron vessel. They were carried out under the supervision of Lieutenant-Colonel Zethations, of the Royal Swedish Navy.

"*Target.*—The hull of a 60-gun frigate, which had been built in 1844; it had been cut down to the battery deck, and the copper removed. Her timbers and planking were quite sound; timbers of oak, about 13 inches square and 1 inch apart; planking of Swedish pine, 5½ inches; bottom strengthened inside with wrought-iron diagonal bands, 6 by 1¼ inch; inside planking running half way up to the battery deck of oak, 6 inches thick. This completes the wooden target.

"On the port side a quadrangular opening was made, and fitted with a construction representing a strong double iron bottom, firmly fastened to an oaken frame that had been put on inside on the four sides of the opening, and with through-going bolts, 1 inch in diameter to the timbers.

"*Torpedoes.*—No. 1: 13 pounds dynamite, enclosed in $\frac{1}{12}$-inch iron case. It was placed on the starboard side, amidships, 7 feet below the water-line and 2 feet 2 inches from the bottom of the ship.

"No. 2: 16 pounds dynamite, enclosed in a glass vessel. It was placed on the starboard side, 7¾ feet below the water line, 3 feet from the bottom of the ship, and 40 feet from her stern.

"No. 3: 16 pounds dynamite, enclosed in $\frac{1}{12}$-inch iron case. It was placed on the port side, 5¾ feet below the water line, 2 feet from the bottom of the ship, and 30 feet from her stern.

"No. 4: 10 pounds dynamite, in a case as above. It was placed on the port side, 6½ feet below the water-line, 2⅙ feet from the bottom of the ship, and 70 feet from her stern.

"No. 5: 13 pounds dynamite, in case as above. It was placed 7⅓ feet below the water-line, 2⅙ feet from the centre of the *iron* bottom.

"These five torpedoes were fired at the same moment.

"Effect of explosion: The hull of the ship was lifted about 1 foot and sunk in 1½ minutes.

"No. 1 mine.—Timbers broken and thrown inside, into the hold, on a space of about 15 by 8 feet; three more timbers on one side of this hole broken; inside oak planking rent off on a length of 14 feet; two iron bands torn up and bent, one of them broken in two places; outside planking torn off on a space of 21 by 12 feet; several planks still higher up broken.

"No. 2 mine.—Timbers blown away on a space of about 8 feet square; inside planking torn off on a length of 20 feet; two iron bands broken and torn up and bent; and outside planking rent off on a space of 19 by 12 feet.

"No. 3 mine.—Timbers blown away on a space of 10½ by 12 feet at one end, and 6 feet at the other; inside planking off for a length of 14 feet; one iron band torn up and one broken; outside planking off on a space of 18 by 25 by 15 feet.

"No. 4 mine.—Timbers blown away on a space 4 by 16 feet; on the sides of this hole ten timbers were broken; two iron bands torn up and one broken; inside planking off for a length of 20 feet; outside planking off for a space of 20 by 23 by 10 feet and 13 feet.

"No. 5 mine.—The gas sphere of this mine had hit the middle of the outside plates on one of the angle-iron ribs. This rib was torn from the timbers and bent up, nearly 2 feet in the middle, but not broken. There was an oval hole in the outside plates, 4 by 3 feet, between two ribs, which ribs, with the plates on edge riveted to them, were bulged out about 5 inches. The inner plate, one large piece was blown up in a vertical position, after having cut all the bolts and rivets, sixty of 1 inch and thirty of ¾ inches, save those that fastened the lower side to the oaken frame and timbers. On a length of 30 feet and height of 20 feet, the bottom, on all sides of the iron construction, had been bent inwards; the greatest bend was about 5 inches; three deck beams above had been broken.

"By the joint effect of all the mines, almost all the iron deck beam knees had been rent from the side, and there was an opening between deck and hull on both sides for a length of about 130 feet."

Of the second series (1874–'75), Commander Sleeman states:

"These experiments were carried out by the Swedish torpedo authorities, to ascertain the effect of different sized charges of dynamite and gunpowder, enclosed in divers cases, and exploded at various distances from a target which represented in all respects, with the exception of the armor, a section of the side of H. M. S. Hercules before the boiler room, she being at that time one of the most powerful vessels afloat.

"Target, 32 feet in length, and fitted into the side of an old line-of-battle ship. Similar in shape to a wing tank, and comprised a double bottom in four water-tight compartments, a wing passage in two water-tight compartments, and two large water-tight compartments in rear of all. It extended from 2 feet above the water-line to within about 5 feet of the vessel's keel. The thickness of the plates forming the target were: Outer bottom, lower portion, $\frac{13}{16}$ inches; part where torpedo took effect, $\frac{3}{4}$ inches. Inner bottom and wing passage bulkhead, $\frac{1}{2}$ inch. Vertical and longitudinal frames, both solid and bracket, $\frac{7}{16}$ inches. The longitudinal frames were bracket frames, with the exception of the second, which was solid and water-tight, with its outer edge about 8 feet below the water-line.. The vertical frames, of which there were seven, were placed 4 feet apart, the central one being solid and water-tight, the others being bracket frames. The ship was moored in 42 feet of water; the charges were detonated, one fuze being used in all but No. 3 experiment, when five fuzes were employed.

"*First experiment.*—Torpedo, 33 pounds of dynamite, enclosed in cylindrical steel case, no air space; height 10.75 inches, diameter 10.75 inches, and thickness $\frac{1}{32}$ inch. It was placed 25.5 feet from the target, opposite No. 7 frame, and 9.25 feet below the surface of the water.

"Effect of explosion: Ship appeared to be lifted bodily. A rivet in the midship longitudinal bulkhead of fore compartment was loosened. The torpedo was fired from the ship, and the shock felt was not very great.

"*Second experiment.*—Torpedo, 47.2 pounds of dynamite, in cylindrical steel case, no air space; height 12 inches, diameter 12 inches, and thickness $\frac{1}{32}$ inch. It was placed 25.5 feet from No. 5 frame, 9.25 feet below the surface of the water.

"Effect of explosion: Ship appeared to be lifted bodily. A leak was started in the outer bottom opposite to charge, caused by the loosening of five rivets.

"*Third experiment.*—Torpedo, 112 pounds of gunpowder, rifle small grain, enclosed in a cylindrical steel case placed inside an iron case, with an air space all round; steel case, $9\frac{1}{2}$ by $22\frac{1}{2}$ by $\frac{1}{32}$ inches; iron case, 33 by 25 by $\frac{1}{4}$ inches. It was placed 12 feet from No. 5 frame, 9.25 feet below the surface.

"Effect of explosion: Centre of ship lifted bodily as if her back was broken; ship then rolled heavily to port. On board, fire engines and troughs displaced several feet; shores and struts started, showing that the shock was considerable. The outer bottom on each side of the centre dividing plate indented to a depth of 1 to $1\frac{1}{2}$ inches; numerous rivets started, and some sheared. The leak was considerable, owing to the number of rivets that were started. The strength of the plates was not considered to be materially affected by the indentations; the rivets, 239 in number, were replaced, and the target prepared for the next experiment.

"*Fourth experiment.*—Torpedo, 33 pounds of dynamite, enclosed as in first experiment. It was placed 15 feet from No. 7 frame, 9.25 feet below the surface of the water.

"Effect of explosion: Ship rolled slightly to port. A bolt securing the midship transverse bulkhead to beam was sheared. No damage done to the target.

"*Fifth experiment.*—Torpedo, 66 pounds of dynamite, enclosed in a steel cylindrical case, no air space, 13.5 by 13 by $\frac{1}{32}$ inches. It was placed 21 feet from No. 3 frame, 9.25 feet below the surface of the water.

"Effect of explosion: A rivet in outer bottom, above water-line at fore end of target, was sheared. A few rivets in outer bottom opposite charge, and two in after compartment, were started, but no leak was perceptible. Several shores slightly displaced.

"*Sixth experiment.*—Torpedo, 33 pounds of dynamite, enclosed as in first experiment. It was placed 12.75 feet from No. 7 frame, 9.25 feet below the surface of the water.

"Effect of explosion: Ship not lifted as much as was the case in No. 3 experiment, but explosion much sharper. On board, fire engines were capsized and vertical shores displaced. Outer bottom opposite charge indented to a depth of about ½ inch, other parts less bulged, and many rivets started.

"*Seventh experiment.*—Torpedo, 33 pounds of dynamite, enclosed as in first experiment. It was placed 4 feet from No. 4 frame, 9.25 feet below the surface of the water.

"Effect of explosion: Effect very great; ship hurled suddenly to starboard. On going on board two minutes after the explosion the fore compartment was found full; the after compartment became full ten minutes later. Shores and struts were considerably displaced, and there was evidence that the ship had sustained a severe shock. Outer bottom injured over an area 14 by 16 feet, the plates being split in all directions; one piece, 5 feet square, was torn completely off, and an irregular hole was formed in the outer skin 14 by 12 feet. In the inner bottom below the wing passage bulkhead a piece, 6 by 9 feet, was blown completely out; the wing passage bulkhead was torn from the longitudinal frame and split from top to bottom. The inner skin above the upper longitudinal frame was torn from the latter and forced in and upwards, but was not otherwise damaged. The vertical bracket frames Nos. 3 and 4, the latter opposite the torpedo, were destroyed, but the solid frame No. 5 was almost uninjured. The outer bottom, where it was not torn off, was forced in 7 feet, or 4 feet beyond where the *inner* bottom had been.

"*Eighth experiment.*—Torpedo, 660 pounds of gunpowder, enclosed in a buoyant cylindrical ¼-inch iron case. It was placed 32.3 feet from No. 4 frame, 29.25 inches (*sic*) below the surface of the water.

"Effect of explosion: The ship and target had been thoroughly repaired, and were in good condition when this experiment was made; the ship was in this case moored in 65 feet of water. No effect was produced on the target by the explosion.

"*Ninth experiment.*—Torpedo, 19 pounds of dynamite, enclosed in a cylindrical steel case with arched ends. It was placed 10.5 feet from No. 3 frame, 9.25 feet below the surface of the water.

"Effect of explosion: Effect produced apparently equal to that by No. 3 charge of 112 pounds of gunpowder at 12 feet; indentation being from ½ to 1¼ inches in the outer skin opposite the torpedo.

"*Tenth experiment.*—Torpedo, 19 pounds of dynamite, enclosed in a case similar to that used in the ninth experiment. It was placed 3.3 feet from No. 7 frame, 9.25 feet below the surface of the water.

"Effect of explosion: Hole produced in outer skin 6.5 feet by 2 to 5 feet; inner skin only bulged and slightly cracked in two places. Above the longitudinal frame a bulge was made in the outer skin 8 by 7 feet, with the above-mentioned hole; below the longitudinal frame the indentation was 14 by 5 feet and 2.1 inches deep, with two horizontal cracks 10 by 13 feet and several inches broad.

"*Eleventh experiment.*—Torpedo, 112 pounds of gunpowder, enclosed in a cylindrical case of $\frac{3}{64}$ inch steel, placed in a $\frac{3}{16}$ inch steel case, with 223 pounds of buoyancy. Ignition effected by a glass igniting bottle. It was placed 5.75 feet from No. 5 frame, 9.25 feet below the surface of the water.

"Effect of explosion: There was but little upcast of water outside the ship, but a great upcast through the ship. She immediately lurched to starboard, and on boarding her, five minutes after, the target was found full of water.

"The effect on the target was as follows, above the second longitudinal frame, where strengthened by the wing passage bulkhead: Outer bottom blown away from the fourth to the sixth frames for a length of 8 feet and a height of 4½ feet, and bent in 6½ feet. Inner bottom bent in and broken through between the fourth and fifth frames, with an irregular hole 8 feet square, and between the fifth and sixth frames a similar sized hole. Wing passage bulkhead was bent in 2 to 3 inches, and riven for a length of 29 feet; in the water-tight middle bulkhead athwartships the rivets in two vertical joints were completely torn away.

"Between the second and third longitudinal frames, and below the wing passage bulkhead, both the inner and outer bottoms were completely blown away for a length of 12 feet and a height of 4 feet. The vertical and horizontal frames between the two bottoms had kept their position unchanged, and excepting that the bracket plate by frame No 6 was bent, cracked, and torn away, the damage they had sustained was limited to some comparatively slight bending. The open hole formed in the target measured 76 square feet in outer bottom and 60 square feet in inner bottom.

"Comparing the effect of this torpedo with the seventh, 33 pounds of dynamite, with the latter charge the breach was made at the cost of the bottom plates as well as the vertical and longitudinal frames, which were completely torn asunder and strained; with the gunpowder charge only the bottom plates were broken through, whilst the plates, whose directions were nearly parallel to the lines of explosive effect, were but little affected."

Twelfth experiment.—After thorough repairs the same target was again subjected to experiments in 1876, as follows:

"Torpedo, 660 pounds of gunpowder, enclosed in a buoyant cylindrical $\frac{1}{4}$-inch steel case with domed ends, and contained in an inner $\frac{1}{16}$-inch steel case. It was ignited by two Von Ebner fuzes, placed in a charge of $\frac{1}{4}$-pound of gunpowder and enclosed in a glass bottle. It was placed 5 feet horizontally from the water-line, 23.75 feet actual distance from target, and opposite No. 5 (middle) frame of target, 29 feet below the surface of the water.

"Effect of explosion: The ship was moored in 54 feet of water. She was lifted by the explosion, rolled over to port, and then settled to starboard, sundry large pieces of timber being thrown up in the air. The outer bottom of the target was broken through above the second longitudinal frame, from the fourth to the seventh frames laterally, and from the top of the target to the second longitudinal frame vertically, the hole made measuring about 9 feet high by 12 feet wide, or about 100 square feet in area. The inner bottom was also broken through between the top of the target and second longitudinal frame, and between the fourth and seventh vertical frames, the hole made being about 75 square feet in area. The bracket frames within the damaged area were but little damaged. The wing passage bulkhead was broken through opposite to Nos. 5 and 7 frames, the holes made being, respectively, 18 and 17 square feet in area Through these holes the force of the explosion had made its way to the horizontal iron deck, forming the top of the target, which was completely broken through a little abaft No. 5 frame, the hole made measuring about 100 square feet in area. A piece of this iron deck, weighing, with the iron fastenings attached to it, about 1,650 pounds was thrown 16 feet against the upper deck beams. The target below the second longitudinal frame was comparatively but little injured. The outer bottom was indented and cracked in one or two places, but the inner bottom was uninjured. In addition to the damage to the target the ship herself sustained serious injury, eleven of the lower deck beams with their knees being broken (six being broken completely across). The main keel immediately under the target was also opened at the scarf, and the back of the ship was apparently broken. The hull had given out laterally to such an extent as to prevent the ship being taken into dock."

DISCUSSION OF THE SCANDINAVIAN EXPERIMENTS.—The following analysis of these experiments is based upon the same principles and is subject to the same qualifications as that already given of the Oberon trials. The last column is only designed as a brief summary of the above quotations, to which reference should be made for detailed information.

Analysis of the Carlscrona experiments.

No. of shot.	Explosive.			Distance. (D)		Angle from nadir. (ϑ)	Mean pressure per square inch. (P)	Remarks.
	Kind.	Submergence. (S)	Weight. (C)					
First series:		*Feet.*	*Pounds.*	*Feet.*	*Inches.*	°	*Pounds.*	
1	Dynamite	7.0	13.0	2	2	90	27,865	Wooden side. Hole 15 by 8 feet through timbers.
2	do	7.7	16.0	3	0	90	20,300	Wooden side. Hole 8 feet square through timbers.
3	do	5.7	16.0	2	0	90	35,765	Wooden side. Hole 10.5 by 9 feet through timbers.
4	do	6.5	10.0	2	2	90	23,395	Wooden side. Hole 4 by 16 feet through timbers.
5	do	7.3	13.0	2	2	90	27,865	Iron side. Oval hole 4 by 3 feet through plates.
Second series:								
1	do	9.2	33.0	25	6	90	1,652	No serious damage.
2	do	9.2	47.2	25	6	90	2,114	Leak from loosened rivets.
3	Rifle powder	9.2	112.0	12	0	90	1,610	Ship shaken severely. Many rivets started.
4	Dynamite	9.2	33.0	15	0	90	3,478	No serious damage.
5	do	9.2	66.0	21	0	90	3,442	Do.
6	do	9.2	33.0	12	9	90	4,358	Severe shock to vessel. No serious injury.
7	do	9.2	33.0	4	6	90	22,040	Hole 14 by 12 feet. Both bottoms ruptured.
8	Gunpowder	29.2	660.0	32	3	130	3,813	No injury to vessel.
9	Dynamite	9.2	19.0	10	6	90	3,958	Ship shaken severely. Plates indented.
10	do	9.2	19.0	3	3	90	19,950	Hole 6.5 by 2 to 5 feet. Inner skin bulged and crushed.
11	Gunpowder	9.2	112.0	5	9	90	3,857	Hole through both bottoms. See detailed notes.
12	do	29.0	660.0	23	9	160	6,114	Hole 100 square feet in outer and 75 square feet in inner bottom. Ship destroyed.

Remembering that the mean pressure developed by a large gunpowder explosion acts for a somewhat longer time than one of equal intensity caused by an explosive compound, it will be noticed that these experiments are entirely confirmatory of the conclusions reached from the Willets Point experiments and the Oberon trials as to the measure of a certainly fatal shock to a first-class ship-of-war—conclusions which were submitted to the Board in print long before the results of these Swedish trials were known in this country.

It will be observed that shots Nos. 8, 9, and 11 all subjected the target to similar mean pressures, viz, 3,900 pounds per square inch; but that only the last did serious injury. This shock is below the usual destructive limit, and its exceptional action in the case of shot No. 11 may have been due to the cause pointed out on page 38 when discussing the vertical angular function in the equation for gunpowder.

Other Miscellaneous Experiments.—The following data, although usually more vague than the foregoing, and referring to hulls weaker than those of modern ships-of-war, are worthy of record and approximate analysis. They are gathered from various sources, those marked by quotations being reported by Commander Sleeman.

Experiments in England.—The Dorothea was blown up in Walmer Roads by Robert Fulton in October, 1805. She was a strongly built Danish brig of 200 tons burden, drawing 12 feet. The charge was 180 pounds of gunpowder ignited under her bottom by clock-work, at a probable distance of about 3 feet. The destruction was complete.

In 1865 H. M. S. Terpsichore, a wooden sloop-of-war, was blown up by Mr. George W. Beardslee, at Chatham, England. The charge was 150 pounds of fine-grain rifle powder, placed on the bottom of the Medway in 22 feet of water, at a distance of 12 feet below the keel, and 2 feet horizontally clear of the side. The explosion made a hole 8 feet in diameter, at a distance from the torpedo of 19 feet measured on a nearly vertical line over the latter.

In 1874 a special target was subjected to trial. It consisted of "a rectangular iron case 20 feet long, 10 feet high, and 8 feet wide, divided into six compartments by means of one longitudinal bulkhead midway between the front and rear faces of the target, and two athwartship bulkheads equidistant from the ends of the target. Thickness of front and rear faces, $\frac{11}{16}$ inches; of longitudinal bulkhead, ¼ inch; of athwartship bulkheads, ⅜ inches.

"Torpedo, 100 pounds of gunpowder enclosed in a star torpedo case and fired by two detonators. It was exploded in contact with the target, 7½ feet below the surface of the water, and 7 feet from top of target.

"Effect of explosion on the target: 'Front of centre compartment destroyed and top blown off. Plate representing inner skin destroyed. Back of centre compartment (rear face of the target) much bulged and penetrated; the hole measured 36 by 15 inches. Large portions of the target were thrown to a height of 150 to 200 feet, and from 80 to 100 yards distance.'

"The effect of explosion on a ship's pinnace, which had been placed 16 feet from and at right angles to the front face of the target, with steam up and canopy and shield in position, was that a large quantity of water was thrown back in the boat, putting the fires out and filling the boat up to her thwarts, but otherwise the boat was uninjured."

Experiments in France.—A series of experiments, terminating in 1875, was conducted by the High Commission for Submarine Defences, to establish general rules for regulating torpedo charges. Several small vessels were destroyed by gun-cotton or gunpowder at Brest, Boyardville, Cherbourg, Lorient, and Toulon. The official reports of those experiments are not available, but in a paper prepared by Lieutenant Audic, of the French Navy, for the *Revue Maritime et Coloniale* (September, 1877), certain data are presented which render possible a partial discussion of these and of a few other foreign trials not elsewhere reported.

For the gun-cotton experiments, the information is tolerably complete; but for those with gunpowder, the kind of powder used, the nature of the enveloping case, and the number of points of ignition, all vitally important elements in an analysis, are wanting. This is specially to be regretted, because the size of some of the charges greatly exceeds those used in any other similar experiments.

In default of information as to these importants points, it has been *assumed* that fine sporting powder was used, with a single point of ignition and an envelope of similar relative strength to those used at Willets Point—conditions fairly probable for the smaller charges, but of such uncertainty for the larger as to render the computations of little value.

The following description of some of the vessels is given by Lieutenant Audic The Prudence had plating on the side opposed to the torpedo, but what it was is not stated in detail. The Wagram, Fulton, Audacious, and the gunboat are not described.

Requin.—Length, 95 feet; breadth, 16 feet; draught, 4. 5 feet.
Express.—Length, 108 feet; breadth, 20 feet; draught, 6. 6 feet.
Marie.—Length, 115 feet; breadth, 21 feet; draught, 7. 2 feet.
Cormoran.—Length, 131 feet; breadth, 25 feet; draught, 7. 7 feet.
Eldorado.—Length, 213 feet; breadth, 39 feet; draught, 10. 8 feet.
Prudence.—Length, 177 feet; breadth, 49 feet; draught, 14. 3 feet.

The meagre facts reported as to the injuries caused by the explosions are given in the last column of the table on page 175.

After the conclusion of the trials in 1875, the following rules were adopted by the French High Commission for regulating the charges of their ground mines:

French charges for ground mines.

Depth of water.	Gun-cotton.	Gunpowder.
	Pounds.	*Pounds.*
26 to 36 feet	550	2, 200
50 feet	660	3, 300
60 feet	880	4, 400
67 feet	1, 100	......
73 feet	1, 320	......
80 feet	1, 540	......

Experiments in Austria.—"The object of this experiment was to ascertain the effect of a very large charge of gun-cotton exploded at some distance from the side of a wooden vessel.

"Target, a wooden sloop.

"Torpedo, 400 pounds of gun-cotton, placed 10 feet below the surface of the water, and 24 feet horizontally from the bottom of the vessel.

"Effect of explosion: Complete destruction of the vessel."

The following experiments were made at Pola, in 1875, "to determine the effect of very heavy charges of dynamite on an iron ponton fitted with a double bottom, similar to that of H. M. S. Hercules."

"Target, an iron ponton 60 feet long and 40 feet beam, with circular ends and fitted with a double bottom, also a condenser and two Kingston valves.

"*First experiment.*—Torpedo, 617 pounds of dynamite. It was 62 feet horizontally from the keel, 53 feet actual distance from the side, and opposite amidships; 40.5 feet below the surface of the water, and 20 feet from the ground.

"Ponton: Draught of water 19 feet, and moored in 62 feet of water.

"Effect of explosion: The ponton moved away bodily a distance of 13 feet; a few rivets in the outer bottom were started, and the outer skin was slightly indented between the frames; the maximum indentation being 1.5 inches. No other damage was sustained by the hull. Several of the screws securing the flanges of the Kingston valves were slightly loosened.

"*Second experiment.*—Torpedo, 585 pounds of dynamite. It was placed 60 feet horizontally from the keel, 48 feet actual distance from the side, and opposite amidships; 36 feet below the surface of the water, and 42 feet from the ground.

"Ponton: Draught of water 19.5 feet, and moored in 74 feet of water.

"Effect of explosion: The ponton, which had been more rigidly moored than in the previous experiment, was moved bodily away a distance of 4 feet. Many rivets were loosened, and a few connecting the angle irons were sheared; also, the outer skin was slightly indented. No damage was done to the condenser or Kingston valves."

Experiment in Germany.—This trial was made at Kiel upon "a large gunboat, greatly strengthened internally by solid balks of timber."

"Torpedo, 200 pounds gunpowder. It was placed nearly under her keel, at a distance of 15 feet.

"Effect of explosion: Complete destruction of the vessel."

Experiment in Turkey.—This trial was made in 1875. It was "carried out by Turkish officers attached to their naval school at Halki, an island in the Sea of Marmora, about 8 miles from Stamboul. It consisted in destroying a Turkish schooner by the explosion of an 100-pound gun-cotton mine in contact with her, moored in 58 feet of water, and 10 feet beneath the surface."

Experiments in the United States.—The earlier experiments by Bushnell, Fulton, Colt, and others were not reported with sufficient precision to permit even an approximate analysis.

The destruction of shipping during the late civil war is well worthy of study,

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although details as to charges, distances, etc., are generally unknown. No little labor has been expended in collecting information; and the following list, prepared from all available authorities, including Confederate officers and the unpublished records of the Navy and War Departments, is believed to be essentially correct and complete:

Steamers destroyed or crippled by torpedoes during the civil war.

Date.	Vessels.					Injured.		
	Name.	Service.	Class.	Tons.	No. of guns.	Where.	Extent.	Torpedo.
December 12, 1862	Cairo	U. S. Navy	Armored	512	13	Yazoo River	Destroyed	Mine.
February 28, 1863	Montauk	do	Monitor	844	2	Ogeechee River	Seriously	Do.
July 22, 1863	Raron De Kalb	do	Armbred	512	18	Yazoo River	Destroyed	Do.
August 8, 1863	Com. Barney	do	Gunboat	513	4	James River	Disabled	Do.
September, 1863	John Farron	U. S. Army	Transport	.....	0	do	Seriously	Do.
October 5, 1863	Ironsides	U. S. Navy	Armored	3, 486	18	Off Charleston	do	Spar.
Unknown	Marion*	Confederate	Unarmored	.....	0	do	Destroyed	Mine.
Do	Ettiwan	do	do	.....	0	do	Seriously	Do.
February 17, 1864	Housatonic	U. S. Navy	Sloop-of-war	1, 240	13	do	Destroyed	Spar.
February 17, 1864	Fish torpedo boat	Confederate	Torpedo boat	.....	0	do	do	Own.
April 1, 1864	Maple Leaf	U. S. Army	Transport	508	0	Saint John's River	do	Mine.
April 6, 1864	Gen. Hunter	do	do	460	0	do	do	Do.
April 9, 1864	Minnesota	U. S. Navy	Flag-ship	3, 307	52	Newport News	Internally	Spar.
April 15, 1864	Eastport	do	Armored	800	8	Red River	Sunk	Mine.
May 6, 1864	Com. Jones	do	Gunboat	542	6	James River	Destroyed	Do.
May 9, 1864	H. A. Weed	U. S. Army	Transport	290	0	Saint John's River	do	Do.
June 19, 1864	Alice Price	do	do	320	0	do	do	Do.
August 5, 1864	Tecumseh	U. S. Navy	Monitor	1, 034	2	Mobile Bay	do	Do.
October 27, 1864	Albemarle	Confederate	Armored	.....	2	Plymouth	do	Spar.
November 27, 1864	Greyhound	U. S. Army	Transport	900	0	James River	do	Coal.
December 8, 1864	Narcissus	U. S. Navy	Gunboat	101	2	Mobile Bay	do	Mine.
December 9, 1864	Otsego	do	do	974	10	Roanoke River	do	Do.
December 9, 1864	Bazley	do	Tug	.....	0	do	do	Do.
January 15, 1865	Patapsco	do	Monitor	844	2	Off Charleston	do	Do.
February 20, 1865	Osceola	do	Gunboat	974	10	Cape Fear River	Crippled	Drifting.
Unknown	Shultz†	Confederate	Transport	.....	0	James River	Destroyed	Mine.
March 1, 1865	Harvest Moon	U. S. Navy	Gunboat	546	3	Georgetown	do	Do.
March 4, 1865	Thorne	U. S. Army	Transport	403	0	Cape Fear River	do	Do.
March 12, 1865	Althea	U. S. Navy	Gunboat	72	1	Blakely River	do	Do.
March 28, 1865	Milwaukee	do	Monitor	970	4	do	do	Do.
March 29, 1865	Osage	do	do	523	2	do	do	Drifting.
April 1, 1865	Rodolph	do	Gunboat	217	6	do	do	Mine.
April 13, 1865	Ida	do	do	104	1	do	do	Do.
April 14, 1865	Sciota	do	do	507	5	Mobile Bay	do	Do.
May 12, 1865	R. B. Hamilton	U. S. Army	Transport	400	0	do	do	Do.
June 6, 1865	Jonquil‡	U. S. Navy	Gunboat	90	2	Ashley River	Seriously	Do.

* Blown up accidentally when planting mines (General Beauregard).

† Flag of truce boat, blown up accidentally by a Confederate mine when returning to Richmond with exchanged prisoners of war.

‡ Injured while raising frame torpedoes.

Two other attempts were made by the Confederates to employ the spar torpedo against Union vessels of war. The first occurred on March 6, 1864, when the steamer Memphis was attacked in North Edisto River; and the second on April 19, 1864, when the steam frigate Wabash was attacked off Charleston. In both instances the vigilance of the watch and the promptness of the officer in command prevented the discharge of the torpedo.

On August 9, 1864, three powder barges lying at the landing at City Point were exploded by a clock-work torpedo placed on board one of them by a spy. The destruction of life and property was terrible.

Earlier in the same year, a wharf-boat at Mound City, Ill., was set on fire and destroyed in like manner. It was 600 feet long, and was loaded with stores and supplies for Admiral Porter's Mississippi squadron.

In the following instances facts have been secured upon which to base an approximate estimate of the intensity of the shock.

In the attack upon the Ironsides on October 5, 1863, the torpedo contained 60 pounds of gunpowder, and was exploded by contact against her side—effective distance probably of 2 or 3 feet. Her injuries, although severe, did not cause her withdrawal from service.

The attack upon the Minnesota on April 9, 1864, was of a similar character, the charge being 53 pounds of gunpowder fired at a depth of about 6 feet below the surface. No copper was torn off or inequality produced on the outside of her bottom, but the transmitted shock caused havoc inside the hull, as appears from the following extract from the report of a board of survey:

"Port after shell-room: First and third futtocks of two frames badly sprung; the diagonal straps sprung off; the deck sprung, nine planks being sprung off from the beams about ¾ inches; the linings of the bulkhead sprung badly; amidship bulkhead started inboard about 6 inches.

"Spirit-room: Forward frame broken; planking sprung; second frame badly sprung; bilge-streak broken and sprung off; third frame sprung; planking sprung outward from timbers about 1 inch; two butts of second bilge-streak sprung up; decks started up; one deck plank broken over the spirit-room.

"The centre of the injury appears to be about 6 feet below the surface of the water. The shelving of the port magazine started; port steerage-bulkhead broken; one ladder broken, and all the rest unshipped; nine deck planks of port steerage broken; in the port after magazine the shelving has been shattered; two butts on the gun-deck started upon the port side at No. 13 gun; seventeen planks from the water-way; two axle-trees on gun-deck broken, and one on spar-deck broken, of 9-inch gun-carriages; two lower half-ports on spar-deck, and two lower half-ports on gun-deck broken; preventive plate for main-channel, next to after one, sprung out about ½ inch; one of the bolts of the crane for spare spars, in the main chains, started 1 inch. The paymaster's store-rooms in the cockpit on the port side show the power of the concussion, all the shelves being broken and disarranged. Carefully examined the outside of the ship abreast of the place of injury, and were unable to find any of the copper torn off, or any inequalities on the bottom of the ship. The bulkhead of the shaft-alley, abreast of the shell-room, started inboard about 6 inches for a distance of 15 feet on the port side.

"The binnacle on the quarter-deck forward of the mizzen-mast unshipped from its pedestal on the bridge and thrown 3 feet towards port side. Number of shell-boxes destroyed (9-inch), 78; number of bags destroyed (9-inch), 32; number of canister broken (11-inch), 5; number of sabots and straps destroyed (9-inch), 110. Three 9-inch gun-carriages are disabled, the fore axle-tree of one being broken in two places, the others badly sprung. Two elevating screws that were attached to the guns on the above carriages were rendered useless by being bent; also the elevating screw of the 11-inch pivot by the same cause. The following equipments are broken and rendered useless: Three 9-inch sponges, two 9-inch rammers, two ordinary handspikes, one roller handspike; also, four tompions and two reinforce sight aprons missing from 9-inch guns on port side."

The torpedo was of an elongated form and was ignited at one end, thus somewhat reducing the normal intensity of action due to its distance, which was probably 2 or 3 feet.

The Commodore Barney (August 8, 1863), had just passed over the torpedo—a large electrical mine, containing about 2,000 pounds of gunpowder—when it was fired from the shore. For the time she was completely disabled, and twenty of her crew were washed overboard, but her hull was not crushed.

The Commodore Jones (May 6, 1864) was blown to fragments by a similar charge exploded under her bottom. The water was from 5 to 7 fathoms deep and the mine rested on the ground. Lieutenant-Commander Barnes states: "Suddenly, and without any apparent cause, she appeared to be lifted bodily, her wheels rapidly revolving in mid-air; persons declared they could see the green sedge of the banks beneath her keel. Then through her shot to a great height an immense fountain of foaming water, followed by a denser column thick with mud. She absolutely crumbled to pieces—dissolved, as it were, in mid-air—enveloped by the falling spray, mud, water, and smoke."

The barge Conklin (50 tons) was totally destroyed at Willets Point in October, 1873. The charge was 188 pounds of mortar powder contained in a barrel torpedo resting on the bottom in 13 feet of water. The draught of the vessel was 5 feet. Some of the fragments were thrown 300 feet into the air.

The Olive Branch, a schooner of 60 tons burden, was blown up at the same place in August, 1878. Two charges, each 50 pounds of mortar powder, were suspended amidships 10 feet apart and 3 feet below the hull. The cases were beer kegs, submerged 7 feet in water 15 feet deep. The torpedoes were fired simultaneously by electricity, and the destruction was complete. (See frontispiece.)

Discussion of the miscellaneous experiments.—Although the details of many of these experiments are not known with sufficient precision to warrant a close analysis, an attempt has been made in the following table to apply the new formulæ to the best of them, and thus to determine, approximately, the probable intensities of action which effected the reported results. The figures are generally in perfect accord with the conclusions indicated by the preceding discussions of the more exact data. The exceptions (two shots against the Wagram and one against the Requin) should have little weight—not only from the lack of details essential to a rigid analysis but also because the charges of gunpowder were so enormous that much was probably unburned.

Analysis of the miscellaneous experiments.

Target.	Explosive.			Distance. (D)	Angle from nadir. (ϑ)	Mean pressure per square inch. (P)	Remarks.
	Kind.	Submergence. (S)	Weight. (C)				
		Feet.	*Pounds.*	*Feet.*	°	*Pounds.*	
Dorothea	Gunpowder	15.0	180	3	180	16,020	Total destruction.
Terpsichore	Rifle powder	22.0	150	19	175	1,403	Hole 8 feet in diameter.
English target	Gunpowder	7.5	100	1	90	18,885	Total destruction.
Marie	Gun cotton	26.2	276	35.6	132	4,172	Leak, but no rupture.
Do	do	39.4	917	54.9	132	5,062	Strained; sank slowly.
Do	do	75.0	1,554	65.8	165	6,144	Stove in.
Express	do	27.2	739	36.1	132	7,892	Destroyed.
Eldorado	do	65.9	1,623	65.9	152	6,033	Crushed; broken in two amidships.
Marie	Gunpowder	23.0	441	22	...	3,330	Unhurt.
Do	do	26.2	1,102	36	...	6,150	Insignificant effect.
Express	do	23.0	441	22	...	3,330	Small leak.
Wagram	do	19.7	441	15	...	5,139	Dangerous leak.
Do	do	28.2	1,323	38	...	7,015	Leak; no rupture.
Do	do	33.7	2,205	46	...	10,090	Do.
Cormoran	do	32.8	1,102	36	...	6,207	Hole 18 by 13 feet.
Requin	do	59.3	2,205	60	...	7,087	Hull intact; rails (*pavois*) carried away.
Do	do	52.5	3,310	53	...	13,550	Cut in two.
Fulton	do	131.0	4,409	122	...	6,456	Crushed; hole 20 feet long.
Gunboat	do	19.4	450	28	...	3,729	Small hole, 3 square feet.
Do	do	15.4	287	18	...	2,948	Destroyed.
Audacious	do	28.9	661	24	...	5,480	11 frames broken; bulwarks destroyed; no hole.
Do	do	40.3	661	33	...	3,677	Keel broken; hole 84 square feet.
Prudence	do	29.2	655	23	...	5,937	Holes through both bottoms, 92 square feet and 78 square feet.
Do	do	10.5	112	4	...	5,136	Holes through both bottoms, 70 square feet and 57 square feet.
Austrian Sloop	Gun-cotton	10.0	400	24	90	8,285	Total destruction.
Austrian ponton	Dynamite	40.5	617	53	180	4,576	Moved 13 feet bodily.
Do	do	36.0	585	48	180	5,075	Moved 4 feet; shaken.
Large gunboat	Gunpowder	25.0 (?)	200	15	180	2,463	Complete destruction.
Turkish schooner	Gun-cotton	10.0	100	1	90	377,450	Do.
Ironsides	Gunpowder	10.0 (?)	60	3 (?)	90	3,710	Severe shock.
Minnesota	do	10.0	53	3 (?)	90	3,205	Do.
Commodore Jones	do	36.0	2,000	30 (?)	180	16,333	Total destruction.
Conklin	Mortar powder	13.0	188	8	180	1,869	Do.
Olive Branch	do	7.0	50+50	3	180	1,421	Do.

This analysis suggests several important conclusions:

I. Except in the uncertain and anomalous gunpowder trials upon the Wagram and the Requin (the former vessel not described, and the latter a very small craft), in every instance where the computed mean pressure exceeded our adopted standard of 6,500 pounds per square inch the vessel was destroyed.

II. The injuries to the Terpsichore, and to the Conklin and Olive Branch at Willets Point, show that an ordinary wooden hull will not always endure an instantaneous mean pressure of 1,500 pounds per square inch.

III. The injuries inflicted upon the Ironsides and Minnesota indicate that 3,000 pounds per square inch exceeds the limit of safety even for a strong wooden hull. The blow received by the latter is especially interesting as fixing her extreme endurance.

IV. The trials upon the Austrian ponton confirm the conclusions as to the effect of a recoil in the target, announced on page 136. If the vessel had been held rigidly in position her double iron bottom would have been severely strained, if not crushed.

V. The discrepancies exhibited by some of the gunpowder experiments, and the remarkable uniformity shown by those with gun-cotton and dynamite, confirm the conclusions reached when testing these explosives in the rings. The time allowed for combustion is subject to so great uncertainty that the problem may almost be regarded as indeterminate for explosive mixtures; and hence gunpowder should never be used in submarine mining when it is possible to replace it with an explosive compound.

Conclusions as to Effective Torpedo Range.—The first point for consideration in summing up this discussion is whether the mean intensity of action, as registered by the gauges, is a true measure of the rupturing strain to which a vessel is subjected by a sub-aqueous explosion.

This matter was carefully considered at the outset, and the reasons for believing that these registered compressions truly measure the shock transmitted from molecule to molecule through the water have been given in the scale discussion at the beginning of this chapter. Although not the only cause for the destruction of the vessel, this molecular action is believed to be the governing one, and, indeed, the only one which can be submitted to a mathematical analysis, or which can be assumed in any sense to be measurable in practice. An exceptionally weak hull may yield because it is traversed by the line of least resistance, or because it cannot resist the racking effect of the explosion; but no allowance can safely be made for such contingencies in a general consideration of the problem for modern ships-of-war.

During the entire progress of these investigations it has been kept steadily in mind that experimental data bearing upon this point would possess great value, and some, fortunately, have been secured.

Thus, by the experiments under solid ice about 9 inches thick, we have seen that, although charges and distances and maximum pressures may vary within wide limits, the line of fracture will always occur where the mean intensity of action by the adopted scale is about 1,700 pounds per square inch.

A still more convincing experimental proof of the accuracy with which ruptures may be predicted from the indications of the scale will be presented in Chapter IV, when reporting the trials made to determine the dimensions of torpedoes to enable them to resist explosions of their neighbors. Although the charges of dynamite varied from 100 to 500 pounds, and the distances within corresponding limits, experience proved that in every case in which the mean pressure exceeded the limit of strength indicated by other shots, rupture was sure to occur. There were eighty-two experiments, and in no single instance did this rule fail.

For example, the following results were obtained with the earlier models—the plain Roman figures (511) denoting harmless mean pressures per square inch; those which crushed the torpedo being printed in full-faced type (**3558**), and those which caused slight corrugation, in condensed type (**1348**).

Buoyant model of 1872	511, 764, **1348, 1348, 3558.**
Buoyant model of 1873	514, 814, 848, 1016, 1112, 1120, **1310, 1358.**
Buoyant model of 1875 A	1116, 1345, **1884, 2498.**
Ground model of 1873 A	501, 667, 709, **818, 940, 1028, 1309.**
Ground model of 1873 B	570, 667, 797, 810, 1109, 1152, **1309.**

The practical value of this method of investigation appears from the fact that by closely analyzing the experiments in this manner, and increasing the strength of the parts showing weakness, models have been devised both of buoyant and ground torpedoes which will resist an instantaneous pressure per square inch far higher than any pattern reported abroad.

Adopting, then, the indications of these gauges as a true measure of disruptive intensity of action, the standard value may be inferred from the data already discussed, viz:

To disrupt wooden target, say 5,000 pounds per square inch.
To disrupt iron target, say 6,500 pounds per square inch.
To disrupt Oberon, say 5,500 pounds per square inch.

The iron target was undoubtedly stronger than the Oberon. Hence, if an instantaneous pressure of 6,500 pounds per square inch be adopted as the measure of a fatal shock to a first-class ship-of-war, the estimate would appear to be certainly safe.

Adopting this value, the following are the extreme destructive ranges of submarine mines charged respectively with dynamite No. 1, gun-cotton, explosive gelatine, and the best sporting powder. The latter are computed both for one central fuze, and for several fuzes distributed uniformly through the mass, at the rate of one per cubic foot.

	Charge.	Horizontal range.	Vertical range.
	Pounds.	*Feet.*	*Feet.*
Dynamite No. 1	100	16.3	18.6
Gun-cotton	100	14.7	17.3
Explosive gelatine	100	18.2	20.3
Sporting powder, 1 fuze per cubic foot	100	3.3	3.3
Sporting powder, 1 central fuze	100	3.1	3.1
Dynamite No. 1	200	22.6	25.9
Gun-cotton	200	20.5	24.1
Explosive gelatine	200	25.3	28.2
Sporting powder, 1 fuze per cubic foot	200	7.4	7.4
Sporting powder, 1 central fuze	200	6.6	6.6
Dynamite No. 1	500	35.0	40.0
Gun-cotton	500	31.7	37.3
Explosive gelatine	500	39.1	43.7
Sporting powder, 1 fuze per cubic foot	500	19.5	19.5
Sporting powder, 1 central fuze	500	16.2	16.2

The small additional range obtained by increasing the charge of the ground mine from 200 to 500 pounds, and the greatly increased cost and difficulty of handling, have governed the board in recommending that in our shallow harbors the former shall be the regular service charge. Five 200-pound mines are regarded as a much more serious obstruction to such a channel than two 500-pound mines.

In concluding this branch of the subject it may be well to repeat that the problem has been treated in the manner usual with works of practical engineering. Abstract theorizing has been avoided, and experiment has been made to enunciate in mathematical language the physical laws and conditions upon which success depends.

The general formula for the extreme destructive range (Δ) of a submarine mine charged with an explosive compound and acting upon a first-class ship-of-war, which has resulted from this investigation and from which the foregoing table has been computed, may be placed under the following form for convenience of application. In any particular case, substitute the numerical values of ϑ, E and C, and find Δ. If the vessel lies at this or at a less distance, she will be destroyed; if at a greater distance, she will escape rupture of the hull. A submergence of the charge properly suited to its size is supposed—say not less than three or four feet for one hundred pounds, and proportionally greater for larger amounts.

$$\Delta = \frac{\sqrt[2.1]{(\vartheta + E)\,C}}{8}$$

By this mode of treatment the results are made general. Suppose, for example, that the strength of the hulls of ships-of-war should be increased. A corresponding change in the constant 8, would indicate the new requirements. Suppose that some new explosive compound should prove to be better suited to the work than dynamite. A new value for the constant E in the general formula just given, is all the change that would be required. It will, therefore, be comparatively easy hereafter to keep pace with modern progress; but it must not be forgotten that there will be need of constant vigilance and of systematic research.

CHAPTER II.

ELECTRICAL FUZES.

General classification.—Testing apparatus.—Coefficients.—Theory of ignition.—Standard of safety.—The Abel magnet fuze, medium tension.—The Abel submarine fuze, medium tension.—The von Ebner fuze, medium tension.—Other European fuzes, medium and high tension.—The Beardslee fuze, medium tension.—The Dowse fuze, medium tension.—The Browne fuze (No. IV), high tension.—The Mowbray fuzes, high tension.—The Giant Powder Company fuze, high tension.—The Smith gold foil fuze.—The Goodyear fuze, high tension.—The Hill fuze, medium tension.—Experimental primings.—The Browne compound fuze, high and low tension.—Special experiments.—Low tension fuzes.—Testing.—The wire bridge.—The priming around the bridge.—Fuzes for the engineer service.—Foreign and American fuzes.—The service cut-off.—Simultaneous ignitions, theory and applications.

The vital importance of the fuze in any system of submarine mining for coast defense, is too evident to require demonstration. It must remain submerged for months or years in the torpedo, where no ocular examination is possible, and yet upon its possessing and retaining an absolute certainty of action will depend the value of the mine. In a word, the fuze is the active agent upon which the efficacy of the whole system is staked.

An elaborate investigation of the conditions upon which its certainty of action depends, involving new apparatus and new methods of research, has accordingly been undertaken at Willets Point. Samples of every variety of fuze which could be obtained in this country, or in Europe, have been subjected to careful tests; the laws of ignition have received mathematical analysis and experimental verification; and the patterns finally adopted are believed fully to meet every requirement.

GENERAL CLASSIFICATION.

Electrical fuzes may be divided into three classes, viz, low tension, for use with strong electrical currents of low potential; high tension, for use with condensed sparks capable of jumping a sensible air-space; and medium tension, specially designed for magneto-electric machines, which generate electricity characterized by a potential higher than the former and less than the latter. This nomenclature is adopted because sanctioned by common use, although the word "tension" is objectionable as no longer employed by many writers on electricity.

Although the three great classes are thus well marked, it by no means follows that a given variety of fuze can only be ignited by a particular kind of electrical generator. While this is true for some varieties, others may be fired by electricity under any of its characteristic forms. For example, the Abel magnet fuze, although belonging to the medium tension class, is not unsuited to frictional machines; and it may also be used with voltaic currents of high electromotive force. As a rule, however, each of the three classes of generators should be provided with a fuze specially adapted to it.

Every electrical fuze suitable for use with explosive compounds should have: 1st, two insulated conductors for conveying the current; 2d, a plug to receive and firmly hold an end of each near to, but not touching, the other; 3d, a small priming suitably arranged for ignition at this point; and, 4th, a metallic cap, containing a detonating charge, usually of fulminating mercury.

The only essential difference between the three classes lies in the manner of causing ignition. The low tension variety usually acts by the heating of a very fine wire uniting the insulated conductors, and embedded in a suitable priming. The second and third classes are fired by the passage of the electricity through a small break in the metallic circuit at this point, the spark igniting a sensitive priming; they differ from each other in the chemical composition and the electrical resistance of this priming.

CONDITIONS COMMON TO ALL FUZES.

Reserving the third of the above conditions for future consideration, the conclusions reached as to the best method of fulfilling the other three may be stated at once. They have been formed after a study of all the numerous devices now exhibited in the torpedo museum at Willets Point, coupled with experimental trials designed to develop their merits and demerits.

I. The insulated conductors should be flexible, tough, and of low electrical resistance. Lake Superior copper wires of good quality, in size about No. 20, B. W. G., and of unequal length (5 inches and 7 inches, respectively) have been adopted.

The insulation must be proof against deterioration from age, a condition which excludes gutta-percha and India-rubber; it is well fulfilled by a closely woven wrapping of cotton thread coated with parafine, or with beeswax, rosin, and tar boiled together. The free ends are bared for about 1.5 inches.

II. The plug must be a non-conductor of electricity, not liable to deteriorate with time and exposure to damp air, nor to corrode the copper wires. Beech wood, kiln dried and coated thickly on the outside with Japan wax, well fulfills these conditions.

The shape must be such as to render any contact between the wires impossible, and to clamp them so firmly that no accidental strain on the free ends can disturb their internal adjustment. The form adopted is the following:

The plug consists of three parts: 1st, a cylinder, 0.25 inches in diameter and 0.7 inches long, grooved longitudinally on its opposite sides to receive the wires. Entirely round the middle is a cut 0.05 inches deep and 0.15 inches wide. The wires with their wrapping of cotton are each pressed into one-half of the longitudinal grooves until they reach the cut; they are then both bent sharply to the left nearly at right angles, and are led through this cut until they have passed half round the cylinder, when they are again bent at right angles and pressed into the other half of the longitudinal grooves. Thus each wire leaves the plug in the opposite groove from which it entered, and at no point can they come in contact with each other. The inside ends of the wire are then bared, scraped, cut to the proper length (about 0.1 of an inch), and prepared according to the class to which the fuze belongs. 2d, of a hollow cylindrical cap with a stout shoulder at one end, leaving a smaller hole for the passage of the free ends of the insulated wires. This cap is made to closely fit the solid cylinder; and the latter, smeared with glue, is forced into it until the end abuts firmly against the shoulder, leaving a small chamber round the bridge to receive the priming. 3d, of a paper disc held in position by a drop of collodion, to close the latter. These several parts are turned by machinery to fit each other accurately, at a trifling cost; and the whole plug is solid, strong, and a perfect protection to the bridge and priming.

IV. The detonating cap is made by punching a disc of stout sheet copper into a cylindrical form, fitting the plug closely. The bottom is solid, and contains 20 grains of fulminating mercury, full weight, held in place by a paper disc secured by a drop of collodion. This charge, which added to the priming amounts to about 24 grains, is found by experiment to be amply sufficient to detonate dynamite in the shape of loose powder, whether soft or frozen. The cap is 1 inch long and 0.4 inches in diameter, and entirely encases the chamber of the plug. It is rigidly attached to the latter, by applying a pressure at two opposite points near the top sufficient to indent them into the wood.

The fuze thus formed is 1.4 inches long and 0.4 inches in diameter. As soon as completed, it is dipped into melted Japan wax, which supplies a uniform water-proof coating to the whole.

MEDIUM AND HIGH TENSION FUZES.

The fundamental distinction between medium and high tension fuzes is based upon the conductivity of their priming. For the former the electrical resistance is easily measurable—varying from a few ohms to about half a megohm. For the latter it is usually immeasurable by ordinary methods and apparatus—often exceeding 10 megohms. This difference cannot be ignored, since its practical effect is to exclude high tension fuzes from use with voltaic batteries and ordinary magneto-electrical apparatus, which rarely develop enough difference of potential to traverse so high a resistance in sufficient quantity to produce ignition. Nevertheless, as the line of demarcation cannot easily be drawn, and as the methods of testing are the same for both classes, it is convenient to treat them together—specifying for each variety the class to which it belongs.

In 1869, when investigations in submarine mining were begun at Willets Point, the electrical fuzes in the market belonged exclusively to the high and medium tension varieties, and were chiefly supplied by the Oriental Powder Company and the Laflin & Rand Powder Company—the former employing as manufacturer H. J. Smith, of Cambridge, Mass., and the latter C. A. Browne, of North Adams, Mass. Both made use of a modification of Jabez B. Dowse's fulminating copper priming, patented on August 27, 1867, which is exceedingly sensitive to electricity. Serious accidents were frequent—indeed, both of the makers suffered severely in their own persons from accidents due to the over-sensitive nature of their fuzes. Nevertheless, as attempts to imitate the Abel priming in this country had failed, and as no safe substitute certain to explode had then made its appearance, the use of these fuzes was general.

In inaugurating a series of experiments which would require many of our soldiers to remain for hours in the close vicinity of loaded torpedoes, it became a matter of primary importance to provide a safe method of ignition.

The most convenient portable apparatus for firing at that date was the improvement upon the von Ebner frictional battery, patented by H. J. Smith in 1869. It required fuzes of the high or medium tension classes to which those named above belong.

These facts made it evident that the subject of electrical fuzes must receive early and systematic attention, and that the high and medium tension classes should be studied first.

In such an investigation, apparatus for comparing the sensitiveness of different primings by accurate measurement was deemed essential. As none had been devised, or at least made public, the task was undertaken at once; and before reporting the results of the experiments, this testing apparatus will receive attention.

Testing Apparatus.—Medium and high tension fuzes generally admit of no individual test to determine in advance their certainty of action, because this chiefly depends on the chemical nature and condition of the priming. The plan which I have sought to develop involves a machine by which known and gradually increasing charges can successively be passed through this priming. Beginning with a charge too small to cause ignition, and successively increasing it by small known increments until explosion occurs, will fully test the individual fuze under trial; and by applying this process to a sufficient number charged with the particular priming to be studied, a good idea, both as to its absolute sensitiveness and as to its uniformity of action, can be formed.

Such a machine, although simple in theory, was by no means easy to devise, for the sensitiveness of some of the primings required it to possess extraordinary delicacy.

After careful consideration, I adopted the idea of Cuthbertson's balance electrometer as promising the best results. Many practical difficulties, not necessary to recount here, were successively overcome before the requisite degree of sensitiveness was secured. The machine as finally perfected in June, 1871 (Plate XX), may be described as follows:

A wooden stand, 16 by 4.5 inches, supports two uprights, each about 6 inches long. One is nearly in the middle of the stand. It is of ebonite, insulating a nickel-plated brass hemisphere, secured, flat side up, on its top. A deep groove across the flat side separates two little holes, 1 inch apart, of which the bottoms are plane surfaces. They are filled with pure mercury, and support the needle points of a curved steel ribbon, secured, near its middle point, to a light aluminum rod, 13 inches long. This rod has a gilded pith ball at one end, and a little bit of rounded soft iron at the other. Its total weight, including the steel ribbon, is 32 grains, of which a differential only is to be overcome when adjusted for extreme delicacy. A nickle-plated brass arm, projecting from the side of the hemispherical ball, supports at the same level a small nickle-plated brass ball, with a plane top. When the aluminum rod is in position, the needle points stand in the mercury, and the pith ball rests on the top of the small brass ball The space between the needle points and the pith ball is graduated into 100 divisions, over which slides a little aluminum weight adjusted to register one grain when at the 100 mark. When this weight rests at zero, the rod is to be accurately balanced by an ivory slide moving on its other half.

Exactly under the soft iron terminal is placed the second upright. It consists of a hollow glass tube, capped by a nickel-plated brass sphere pierced with a vertical hole. Contained within the glass tube, with one end slightly projecting above the sphere, is a little magnet. By a vertical sliding motion which can be given to the upright, the distance between the magnet and the soft iron terminal can be regulated on an attached scale at pleasure. The usual distance is half an inch.

The projecting arm of the middle upright is connected by an insulated wire with a mercury cup on the stand, which is similarly connected with the positive conductor of an electrical machine, made after the Smith pattern, and also with the inner coating of a condenser of which the other terminal is put to earth. Condensers of various capacity from 0.00016 microfarads upwards are employed, all suited for high potentials. The negative conductor of the electrical machine is put to earth.

One insulated leading wire of the fuze to be tested is put to earth, and the other to the brass ball of the magnet upright. All sharp ends of leading wires are coated with sealing-wax to prevent leakage.

When the electrical machine is excited the positive electricity passes through the mercury cup on the stand to the condenser, and charges it to a degree proportional to the potential of its free electricity; the latter is also equally distributed over the prime conductor, and the whole apparatus supported by the middle insulated upright. When this potential becomes sufficiently great to overcome, by the repulsion acting on the pith ball, the inertia of the aluminum rod (loaded to any desired degree by the movable weight), the pith ball rises. The soft iron terminal, already in the magnet field, is then instantly attracted and brought by the magnet into contact with the brass ball supporting it. The condenser is thus discharged through the fuze, which is exploded, or not, according to its degree of sensitiveness. A small gold-leaf or pith-ball electroscope, connected with the inner coating of the condenser, reveals the proper working of the instrument to the eye. Care must, of course, be taken to avoid any dampness on the apparatus, and to move the handle of the electrical machine steadily and uniformly, stopping at the instant when the pith ball begins to move.

By beginning with a charge known to be too feeble, and increasing gradually by small regular increments, the minimum amount required to effect an explosion is ascertained. Applying this test to a sufficient sample, the character for uniformity and sensitiveness of any lot of high or medium tension fuzes may be determined; and by a subsequent repetition any change caused by lapse of time may be detected.

This apparatus is so delicate that, although severe shocks may be given if desired, more than one hundred successive charges, each larger than the preceding by a definite quantity, may be sent through the human body before the senses begin to take note of them.

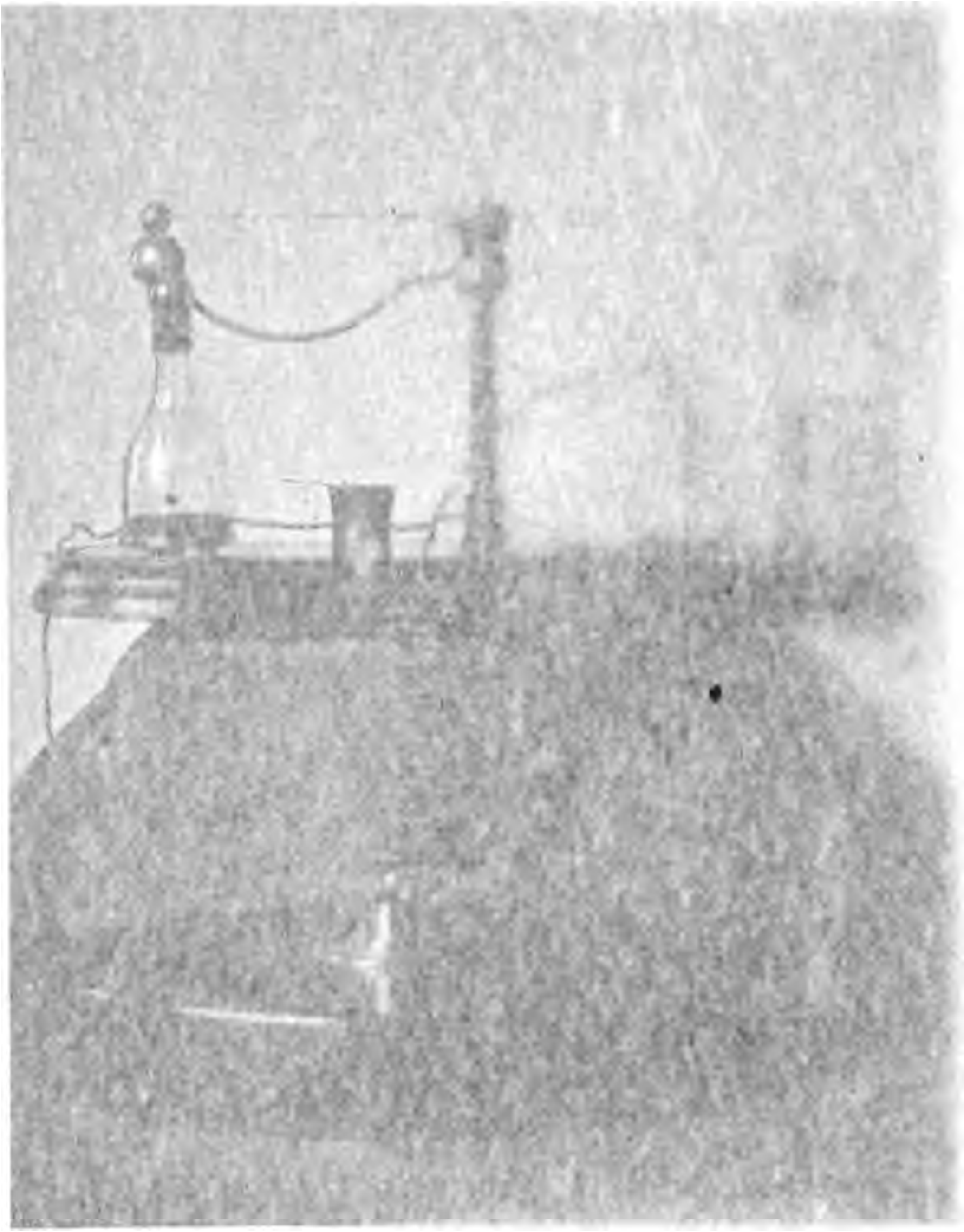
As already stated, the electrometer above described contains several successive improvements, introduced from time to time after the beginning of the experiments; and in comparing the different tests of the same kind of fuze given in the tables, it may be useful to know when these changes were made.

The instrument was first used on July 3, 1870. The movable arm was then balanced on knife edges; the magnet had not been added; the electricity was generated by an ordinary glass-plate machine; and a Leyden jar, with a chain connection between the knob and inner coating, was the only condenser employed.

On April 21, 1871, I discovered that the knife-edge contacts were defective, as a glow could be seen passing in the dark. They were replaced by the needle points plunged in mercury. A mercury contact for the down stroke was also added, in order to check a tendency to ballot and thus to deliver the charge by instalments. These arrangements were first used on June 11, 1871.

Further trials showed that the tendency to ballot was still a serious defect, and on June 28, 1871, the electrometer was finally perfected by adding the magnet. The plate machine, however, continued in use.

In damp weather much trouble was experienced in keeping this plate machine in good working order; and, moreover, being connected with the opposite coatings of the jar, it occasioned a slight loss of charge during the time (about 0.4 of a second) which was required for the movable arm to perform its duty after beginning to move. This defect was obviated by replacing it by a frictional machine made to order, upon the pattern devised by H. J. Smith for his apparatus for discharging tension fuzes in



[illegible] with the pith ball rises. The soft iron armature, already [illegible] is then instantly attracted and brought by the magnet [illegible] supporting it. The condenser is thus discharged through the [illegible] or not according to its degree of sensitiveness. A small [illegible] telescope, connected with the inner coating of the condenser, [illegible] of the instrument to the eye. Care must, of course, be [illegible] the apparatus, and to move the ball of the electrified [illegible] stopping at the instant when the pith ball begins to [illegible] with a charge known to be too feeble, and then [illegible] the minimum amount required to effect an explosion [illegible] this test to a sufficient sample, the character [illegible] lot of high or medium tension fuzes may be determined [illegible] any change caused by lapse of time may be detected [illegible] is so delicate that, although severe shocks [illegible] successive charges, each larger than the preceding [illegible] be sent through the human body before the same [illegible]

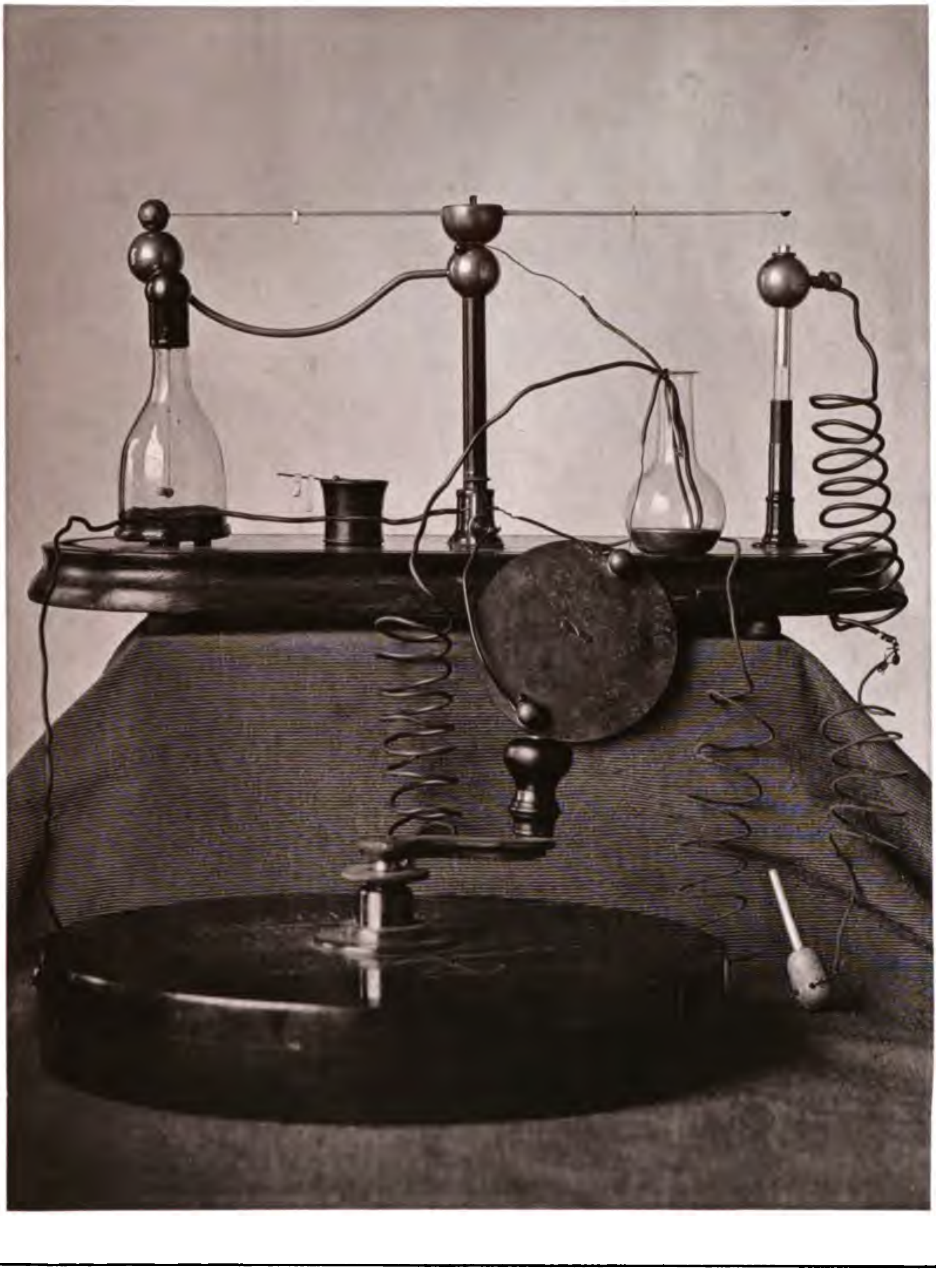
As already stated, the electrometer above described contains several [illegible] improvements introduced from time to time after the beginning of the [illegible] and in comparing the different tests of the same kind of fuze given in the [illegible] may be useful to know when these changes were made.

The instrument was first used on July 3, 1870. The movable arm was balanced on knife edges; the magnet had not been added; the electricity was generated by an ordinary glass-plate machine; and a Leyden jar, with air [illegible] between the outer and inner coating, was the only condenser employed.

On April 21, 1871, I discovered that the knife-edge contacts were defective; glow could be seen passing in the dark. They were replaced by the [illegible] plunged in mercury. A mercury contact for the down stroke was also added to check a tendency to ballot and thus to deliver the charge by [illegible] arrangements were first used on June 11, 1871.

Further trials showed that the tendency to ballot was still [illegible] on June 28, 1871, the electrometer was finally perfected by adding the [illegible] plate machine, however, continued in use.

In damp weather much trouble was experienced in keeping this [illegible] good working order; and, moreover, being connected with the [illegible] the jar, it occasioned a slight loss of charge during the time [illegible] which was required for the movable arm to perform its duty after [illegible] This defect was obviated by replacing it by a frictional machine made [illegible] pattern devised by H. J. Smith for his apparatus for [illegible]



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ordinary blasting. The plate (a disc of ebonite) revolves between cushions in an air-tight box of ebonite, and the external terminals consist of small polished brass knobs, which permit but very little of the charge to be dissipated. The leading wires have always been kerite-coated, and tipped with sealing-wax. With this new machine, which was first used on October 25, 1872, no further trouble was experienced.

After this date the only change was the introduction, in February, 1874, of several new condensers having different capacities, in order to facilitate the testing of fuzes differing widely in sensitiveness. These condensers were made by bedding opposed plates of tinfoil in soft ebonite, and then subjecting the whole to the process of vulcanization. Being thus protected from the air no film of moisture could collect on the dielectric, as is often the case with a common Leyden jar.

Coefficients of the Electrometer.—This electrometer, of course, registers its results in terms of the electrical repulsion exerted between the fixed brass ball and the movable pith ball; *i. e.*, its natural scale is entirely arbitrary. To reduce the readings to recognized electrical units was desirable for several reasons, and it was accomplished in the following manner:

The explosion of the fuze is caused by the passage through it of the charge of the condenser increased by the free electricity distributed over the insulated part of the apparatus. This total charge is measured by the product of the sum of the capacities of the condenser (K) and of the insulated surface ($K_{,}$) expressed in microfarads, by the difference of potential between the opposed plates (P) expressed in volts. To send this charge through the fuze, the repulsive force acting between the fixed brass ball and the movable pith ball must raise the weight registered on the scale in hundredths of grains (F), increased by the resistance of the inertia developed in the movable arm (F′). But by the well-known law of Coulomb, the repulsive force between two bodies similarly charged with electricity is proportional to the product of their charges, a product which in this case may be assumed to be proportional to the square of the total charge. Hence we have the fundamental equation of the machine:

$$(K + K_{,})\, P = A \sqrt{F + F'} \tag{40}$$

In this equation K and $K_{,}$ admit of exact measurement, F′ and A (the latter for a given condenser) are constants, and F is the reading of the electrometer scale. Hence, if any plan can be devised by which a series of numerical values for the first member corresponding to known values of F can be determined, the values of A and F′ can be found by the method of least squares. This done, by noting F, it will be easy to compute for any charge which is sent through the fuze both the quantity in microfarads and the potential in volts. These determinations were made in the following manner:

In a Thomson reflecting galvanometer the swings of the beam of light, corrected in the usual way for the resistance of the air, etc., are proportional to the charges sent through the coils; *i. e.*, in this case to $(K + K_{,})\,P$. The numerical values of K for any condenser, and that of $K_{,}$ as well, may be found from a standard condenser by Law's method. By the same method the value of P (electromotive force in volts) may be found for any battery by comparing its swing with that of a standard Clark cell whose electromotive force in volts is known.

Hence, by placing a Thomson reflecting galvanometer in place of the fuze with my apparatus, noting the swings corresponding to a series of known values of F, and comparing the latter with swings produced by known charges of a standard condenser expressed in microfarads, the desired result may be accomplished. This was done in the spring of 1874.[*]

Several condensers differing in capacity were needful to adapt the apparatus to fuzes of different degrees of sensitiveness. A small Leyden jar, whose inner and outer coatings were each 39 square inches, was used at first, but after April, 1874, it was usually replaced by other condensers better suited for so delicate work. Of these, one known as the mica condenser was made at Willets Point by bedding in paraffine wax two plates of tinfoil separated by a sheet of mica. Each plate contained 4 square inches of surface. Two other condensers, designated respectively as No. 1 and No. 2, were subsequently made to order by the Laflin & Rand Powder Company, of New York. The former consisted of two plates of tinfoil 3 inches in diameter, bedded $\frac{1}{32}$ of an inch apart in soft ebonite subsequently vulcanized. The latter was identical in construction, but the plates were 6 inches in diameter. The capacities of these four condensers were very carefully determined by comparing them with two standards made in London—one (half a microfarad) by Elliott Bros., and the other (one-third of a microfarad) by Warden & Co. These two standards differed less than 1 per cent. from each other, and the mean of their indications was adopted. The following table exhibits the results of several measurements of these fuze-testing condensers made at different dates, in different places, by different observers, and with widely different battery power. The means are adopted in the final reductions now reported:

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[*] It may be well to remark that the practical use of the apparatus was not delayed until the results of this analysis had been reached. As soon as the electrometer was perfected, and even before the final form had been adopted, the various fuzes in the market were tested; original primings were submitted to experiment; and the manufacturers of electrical fuzes in this country were encouraged to present new compositions for trial. This was frequently done, and with the happiest results; for by this means the dangerous fulminating copper priming was replaced by safe compositions, and the needless sacrifice of life on the Hoosac tunnel and other public works was brought to an end. Letters from these gentlemen, now on file at Willets Point, attest these facts, and establish the practical utility of a systematic study of the problem. The natural scale of the electrometer was employed in this work; *i. e.*, the fuzes were compared by the electrical repulsion in hundredths of grains Troy needful to send a charge sufficiently large to cause their explosion.

Capacity of fuze-testing condensers.

Date.	Cells used.		Measured capacity in microfarads.				
	Number.	Electromotive force in volts.	Apparatus without condenser.	Leyden jar.	Mica condenser.	Condenser No. 1.	Condenser No. 2.
February 11, 1874	50	59. 0	....	0. 00148	....	....	....
February 12, 1874	50	60. 5	....	0. 00132	....	....	....
February 14, 1874	50	60. 0	....	....	0. 000563	....	....
April 3, 1874	100	121. 2	....	....	....	0. 000218	....
April 10, 1874	500	245. 0	....	0. 00140	....	0. 000209	....
April 27, 1874	500	219. 4	....	....	....	0. 000157	0. 000534
April 27, 1874	600	340. 0	....	....	....	0. 000165	0. 000538
February 27, 1879	1, 200	628. 0	....	....	....	0. 000179	0. 000538
March 3, 1879	1, 200	645. 0	0. 000153	....	....	....	....
Means			0. 000153	0. 00140	0. 000563	0. 000186	0. 000537

The determination of the numerical values of the constants A and F′ in equation (40) by sending successive charges through the coils of a Thomson galvanometer placed in the circuit designed for the fuzes, was an operation of extreme delicacy; but it was successfully accomplished with the efficient assistance of officers of the Battalion of Engineers. The galvanometer was a very good one, made by Elliott Bros., of London, and had a resistance of 5753 ohms at 19° Centigrade. For each adjustment of the weight on the movable arm of the electrometer, from ten to fifteen successive charges were sent through the galvanometer. The corresponding mean number of divisions passed over by the beam of light (corrected for the resistance of the air) was adopted, and is reported in the following table—which, therefore, includes the results of over 600 separate measurements. The observations were begun in each case at the zero of the electrometer scale, and were continued up to the limit of the scale for measuring the swings of the beam of light. No shunt was used.

The figures in the columns of the following table headed "Computed swings," are those given by the formulæ deduced below; and attention is invited to the close accordance between them and the observations—which is also exhibited to the eye on Plate XXI. The columns headed "No condenser," exhibit measurements made to determine the charges due to the insulated surfaces of the apparatus with no condenser attached. The columns relating to the Leyden jar will be explained below:

Observations for condenser constants.

Electrometer reading.	No condenser.			Condenser No. 1.			Condenser No. 2.			Jar and chain.			Jar and wire.		
	Obs. swing.	Comp. swing.	Diff.	Obs. swing.	Comp. swing.	Diff.	Obs. swing.	Comp. swing.	Diff.	Obs. swing.	Comp. swing.	Diff.	Obs. swing.	Comp. swing.	Diff.
$\frac{1}{100}$ *grs.*	*Divs.*	*Divs.*		*Divs.*	*Divs.*		*Divs.*	*Divs.*		*Divs.*	*Divs.*		*Divs.*	*Divs.*	
0	30	15	+15	71	65	+ 6	182	130	+52	25	29	− 4	361	295	+ 66
1	...	...	....	118	106	+12	204	212	− 8	122	116	+ 6	608	482	+126
2	...	...	....	148	135	+13	310	271	+39	183	211	−28	...	...	....
3	...	...	....	158	159	− 1	323	319	+ 4	278	305	−27	...	...	....
4	...	...	....	179	180	− 1	359	360	− 1	444	395	+49	...	...	....

Observations for condenser constants—Continued.

Electrometer reading.	No condenser.			Condenser No. 1.			Condenser No. 2.			Jar and chain.			Jar and wire.		
	Obs. swing.	Comp. swing.	Diff.	Obs. swing.	Comp. swing.	Diff.	Obs. swing.	Comp. swing,	Diff.	Obs. swing.	Comp. swing.	Diff.	Obs. swing.	Comp. swing.	Diff.
$\frac{1}{100}$ *grs.*	*Divs.*	*Divs.*		*Divs.*	*Divs.*		*Divs.*	*Divs.*		*Divs.*	*Divs.*		*Divs.*	*Divs.*	
5	...	...	....	195	198	− 3	408	397	+11	544	481	+63	...	...	....
6	...	...	....	196	215	−19	394	431	−37	...	...	....	...	...	....
7	...	...	....	212	231	−19	456	463	− 7	...	...	....	...	...	....
8	...	...	....	228	246	−18	465	493	−28	...	...	....	...	...	....
9	...	...	....	258	260	− 2	508	520	−12	...	...	....	...	...	....
10	64	64	0	257	273	−16	529	547	−18	...	...	....	...	...	....
12	...	...	....	298	297	+ 1	595	596	− 1	...	...	....	...	...	....
14	...	...	....	338	320	+18	644	642	+ 2	...	...	....	...	...	....
15	...	...	....	...	...	....	657	663	− 6	...	...	....	...	...	....
16	...	...	....	342	341	+ 1	693	684	+ 9	...	...	....	...	...	....
17	...	...	.. .	...	...	....	706	705	+ 1	...	...	....	...	...	....
18	...	...	....	357	361	− 4	...	...	....	...	...	....	...	...	....
20	87	90	− 3	343	380	−37	. .	...	....	...	...	....	...	...	....
25	...	...	....	430	424	+ 6	...	...	....	...	...	....	...	...	....
30	...	...	....	480	464	+16	...	...	....	...	...	....	...	...	....
35	...	...	....	516	500	+16	...	...	....	...	...	....	...	...	....
40	129	126	+ 3	540	535	+ 5	...	...	....	...	...	....	...	...	....
45	...	...	....	564	566	− 2	...	...	....	...	...	....	...	...	....
50	...	...	....	594	596	− 2	...	...	....	...	...	....	...	...	....
70	169	167	+ 2	...	...	....	...	...	....	...	...	....	...	...	....
100	198	199	− 1	...	...	....	...	...	....	...	...	....	...	...	....
Sums	677	661	24	6, 822	6, 852	218	7, 433	7, 433	236	1, 596	1, 537	177	969	777	192

The manner in which the formulæ were derived from these observations, is next to be considered. The discussion of the data for the apparatus without a condenser and with condensers Nos. 1 and 2, offered no peculiar difficulty, and they will be treated first.

It is apparent that the constant F' in equation (40) depends for its value upon the resistance offered by the inertia developed in the movable arm when exactly balanced. As this arm weighs only 32 grains, and is supported on two needle points, such a quantity is too small to be directly measured. It was thought best, therefore, to treat it as an unknown quantity in each case, and to adopt the mean of the three values resulting from the analysis. There are then two unknown constants, F' and A (the latter for each condenser), to be determined from these observations.

Since the first member of equation (40) is directly proportional to the swings of the beam of light (S), it may be temporarily replaced by that quantity, A becoming $A_{,}$; giving:

$$(41) \qquad S = A_{,}\sqrt{F + F'}.$$

The first step was to deduce the most probable values for $A_{,}$ and F' from the several recorded values of S and $\mathcal{F}$. For this purpose, the equation was put under the following form, suitable for applying the method of least squares, $A_{,,}$ representing $\frac{1}{A_{,}^{2}}$:

$$S^{2} A_{,,} - F' - F = 0.$$

There are six equations of condition for the apparatus without a condenser, the last based on double the usual number of observations; twenty-two equations for condenser No. 1; and sixteen equations for No. 2. The following are the several normal equations, and the resulting values of the constants.

Without a condenser.

$$4{,}241{,}437{,}811A_{,,} - 136{,}175F' - 10{,}698{,}050 = 0.$$

$$136{,}175A_{,,} - 7F' - 340 = 0.$$

Hence: $A_{,} = 19.7.$

$$F' = 1.09.$$

Condenser No. 1.

$$552{,}362{,}376{,}918A_{,,} - 2{,}613{,}004F' - 76{,}328{,}585 = 0.$$

$$2{,}613{,}054A_{,,} - 22F' - 361 = 0.$$

Hence: $A_{,} = 84.9.$

$$F' = 0.11.$$

Condenser No. 2.

$$1{,}289{,}004{,}333{,}943A_{,,} - 3{,}866{,}911F' - 43{,}819{,}136 = 0.$$

$$3{,}866{,}911A_{,,} - 16F' - 129 = 0.$$

Hence: $A_{,} = 167.4.$

$$F' = 0.558.$$

Remembering that the unit of the electrometer scale is one hundredth of a grain Troy, these three deduced values of F′ (1.09, 0.11, and 0.558) are sensibly the same quantity; and the mean, 0.6, was accordingly adopted. Substituting this value in equation (41), the corresponding values of $A_{,}$ were directly computed for each observation, and a mean of the results for each condenser was adopted; giving the following equations for the swing of the beam of light for any desired value of F.

(42) Without a condenser, $S = 19.8 \sqrt{F + 0.6}.$

(43) With condenser No. 1, $S = 83.8 \sqrt{F + 0.6}.$

(44) With condenser No. 2, $S = 167.9 \sqrt{F + 0.6}.$

The remarkable precision with which these formulæ represent the observations, already shown by the foregoing table, is also exhibited to the eye by Plate XXI; and the result of the analysis certainly leaves nothing to be desired. The next step is to translate the swings of the beam of light into microfarads.

Denote by Q the quantity of electricity, or the amount of the electric charge expressed in microfarads; by K, the capacity of the condenser, and by $K_{,}$, the capacity of the insulated part of the electrometer apparatus, both expressed in microfarads; by P, the difference in electrical potential which causes the passage of the charge through its circuit, expressed in volts; and by B, a constant. Then, since the swing of the beam of light (S) is directly proportional to the charge traversing the galvanometer coils, we have for any condenser (detached from the apparatus):

$$Q = KP = BS.$$

In this expression B is a constant for any particular setting of the magnet of the galvanometer; and its numerical value can be directly determined by observing the swing corresponding to any known values of K and P.

But immediately after the foregoing observations with each condenser had been completed, and before any change had been made in the position of the magnet of the galvanometer, observations were made to determine this value, accurately, by using the standard half-microfarad condenser charged successively by batteries of measured and widely different electromotive force. Thus:

For the setting used with condenser No. 1 (April 3, 1874):

$$B = \frac{0.5 \times 121.2}{28{,}300} = 0.002141$$

For the setting used with condenser No. 2 (April 27, 1874):

$$B = \frac{0.5 \times 219.4}{46{,}200} = 0.002376$$

$$B = \frac{0.5 \times 2.918}{628} = 0.002323$$

$$B = \frac{0.5 \times 5.836}{1230} = 0.002372$$

Mean value, 0.002357

For the setting used with the insulated part of the apparatus (March 3, 18,9):

$$B = \frac{0.5 \times 648}{164{,}750} = 0.001966$$

$$B = \frac{0.5 \times 228}{57{,}900} = 0.001969$$

$$B = \frac{0.5 \times 415}{105{,}500} = 0.001967$$

$$B = \frac{0.5 \times 1.456}{370} = 0.001967$$

Mean value, 0.001967

All the data needful for transforming the equations for the swings of the beam of light, already deduced, into equations of which the units are microfarads and volts, have now been obtained. Thus, equation (41) becomes:

$$(45) \qquad Q = (K + K_{,})\,P = B\,S = BA_{,}\sqrt{F + F'}.$$

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And substituting the numerical values of B and $A_,$ and F′, and reducing:

(46) Without a condenser, $Q = K_{,}P = 0.03896 \sqrt{F + 0.6.}$
(47) With condenser No. 1, $Q = (K + K_{,})\, P = 0.1794 \sqrt{F + 0.6.}$
(48) With condenser No. 2, $Q = (K + K_{,})\, P = 0.3962 \sqrt{F + 0.6.}$

These equations express in microfarads the quantity of electricity sent through the circuit for any reading (F) of the scale of the electrometer; which, it will be remembered, is graduated in hundredths of a grain Troy. To transform them to express the difference of potential which causes the charge to traverse the circuit, it is only needful to substitute the numerical values of K and $K_{,,}$ given in the table on page 187, and reduce. Thus:

(49) Without a condenser, $P = 254.7 \sqrt{F + 0.6.}$
(50) With condenser No. 1, $P = 529.1 \sqrt{F + 0.6.}$
(51) With condenser No. 2, $P = 552.9 \sqrt{F + 0.6.}$

The values of the coefficient of the radical in these equations illustrate the importance of using a condenser with my electrometer. It fulfills two objects: (1) it holds the charge bound, so that the loss during the instant which intervenes between the starting of the movable arm and its closing the circuit is reduced to a minimum; (2) it tends to cause a uniform increase of the charge as received from the frictional machine, thus preventing the apparatus from acting by pulsations.

From the principle of the instrument, the size of the jar can have nothing to do with the potential which causes the discharge; *i. e.*, the coefficient of the radical in these equations should be a constant. That the observations show it to be so, is evident from the values deduced with the three different condensers (the last to be subsequently explained), viz:

Condenser No. 1; capacity, 0.000186; coefficient, 529.1
Condenser No. 2; capacity, 0.000537; coefficient, 552.9
Leyden jar; capacity, 0.001400; coefficient, 528.7
Mean, 536.9

Adopting this mean, we have for the general potential equation applicable with any condenser:

(52) $P = 536.9 \sqrt{F + 0.6.}$

A comparison of this equation with equation (49) exhibits the combined effect produced by the two causes above mentioned. Accordingly, the apparatus has never been used without a condenser, except in testing a few fuzes made with a priming so sensitive to electricity as almost to exceed belief. For these fuzes, the instrumental irregularities were fairly corrected by the manner in which equation (46) and equation (49) were deduced.

It is evident that equation (52) indicates a mode of severely testing the precision of the foregoing analyses; for when F is 0.4, P becomes 536.9 volts, and hence, if the poles of a battery having this electromotive force were connected with the two terminals of the apparatus, motion should take place. This experiment was tried with a battery having an electromotive force of about 630 volts, and the result verified the theory.

It only remains to deduce the equations applicable to the mica condenser and to the Leyden jar.

The former was used only a few times before it was injured by an accident; and no discharge observations were made with it and the galvanometer. Its capacity was measured on February 14, 1874; and it differed so little from that of condenser No. 2 that the same equation may be adopted for both of them. This is evident from the fact that these capacities were respectively 0.000563 and 0.000537 microfarads, giving a ratio practically unity, viz:

$$\frac{0.000563 + 0.000153}{0.000537 + 0.000153} = 1.038.$$

The Leyden jar, as already stated, was used in all the measurements prior to March 30, 1874, and occasionally afterward. Hence, to determine its equation accurately became a matter of importance; but a vexatious difficulty was encountered at the outset. As usual, the knob was connected with the inner coating of tin foil by a brass chain resting upon the latter. On attempting to measure the capacity, it was discovered that this contact was too imperfect to be passed by the voltaic current, and it was necessary to insert an elastic wire spiral before the work could be done. This mechanical detail was a matter of no importance; but when the charge was sent by the electrometer through the galvanometer, an extraordinary difference was developed between the two arrangements for the contact. With the chain, a large part of the smaller charges used in these investigations remained in the jar, and did not traverse the external circuit at all! This is exhibited so plainly by the eleventh and fourteenth columns of the table on page 187, that the fact requires no further demonstration. How to deduce a satisfactory correction did not at first sight appear easy.

The first step was to deduce a formula for the swing of the beam of light when the Leyden jar, with a good wire contact between its knob and inner coating, was used with the electrometer. An attempt to deduce this equation by direct trial failed, because the capacity was so large that observations could not be made when the electrometer reading exceeded unity; and even at zero and unity the motion was so excessive as to give results discordant among themselves. In other words, the galvanometer was too sensitive for the above method, with so large a condenser.

When the equations with condensers No. 1 and No. 2 were deduced, the positions of the magnet had been made as closely as possible identical; and a comparison between the coefficients of the radical showed them to be nearly proportional to the capacity $(K + K_{,})$. Thus, for $F = 0.4$, equation (43) becomes $S = 83.8$; and equation (44) $S = 167.9$. The ratio of these quantities is:

$$\frac{167.9}{83.8} = 2.004.$$

The ratio between the corresponding capacities is:

$$\frac{0.000537 + 0.000153}{0.000186 + 0.000153} = 2.035.$$

This verification of what theory would indicate made it proper to compute the value of the coefficient of the radical in the equation for the swing of the beam of light with the Leyden jar, from the known capacities and from the coefficients for condensers No. 1 and No. 2. Thus, from the former it would be:

$$\frac{0.001400 + 0\ 000153}{0.000186 + 0.000153} \times 83.8 = 384.$$

And from the latter:

$$\frac{0.001400 + 0.000153}{0.000537 + 0.000153} \times 167.9 = 378.$$

The mean, or 381, was adopted, giving:

(53) With Leyden jar and wire, $S = 381 \sqrt{F + 0.6}$.

This equation accords sufficiently well with the few direct observations to bring its indications within the limits of error due to magnet adjustment, as is shown by the table on page 187.

The corresponding value of B was assumed to be 0.002155, the mean of the three measured values given above. Hence, for the quantity and potential equations of the apparatus, with the Leyden jar, and a good wire contact between the knob and inner coating:

(54) $Q = (K + K_{,})\, P = 0.821 \sqrt{F + 0.6}$.

(55) $P = 528.7 \sqrt{F + 0.6}$.

These equations compare well with those for the other condensers, and may safely be considered to apply to the few observations made when the wire was inserted in the jar. How to deduce the more important formula for Q when the chain contact had been used remains to be considered.

The observations in the table on page 187 show that the effect of this bad contact had been to cause the retention of a portion of the charge in the jar, thus in effect reducing its capacity by an amount varying with the potential. The first step was to compute from these observations what had been the capacities actually available.

This was done by substituting for S in the following equation, each *observed* swing, with the corresponding value of F, and computing the value of K. The equation is found by transforming equation (45) and substituting the numerical values of the constants given above.

$$K = \frac{0.002155\,S}{528.7\,\sqrt{F + 0.6}} - 0.000153.$$

The following table exhibits the effective values of K thus found (K′), and the actual loss of capacity (m), both expressed in microfarads:

$F = 0$	$S = 25$	$K' = -0.000022$	$m = 0.001422$
1	122	+ 0.000182	0.001218
2	183	+ 0.000310	0.001090
3	278	+ 0.000444	0.000956
4	444	+ 0.000691	0.000709
5	544	+ 0.000784	0.000616

Considering the figures in the last column, and the theoretical conditions which must be fulfilled, the loss (m) evidently diminishes as F increases, nearly as the ordinates of a curve which may be represented by the equation:

$$m = \frac{y}{F + x}$$

But when F is zero, the *true* value of m must be 0.0014—since in no case can it *exceed* that quantity as indicated by the above figures. Hence:

$$x = \frac{y}{0.0014}$$

Substituting this value of x, we have:

$$m = \frac{y}{F + \frac{y}{0.0014}}$$

$$y = \frac{0.0014\,F\,m}{0.0014 - m}$$

Substituting in these equations the several corresponding values of m and F, derived from the last table, and taking a mean of the resulting values of y, we find by reduction:

$$y = 0.0075$$
$$x = 5.357$$

Hence:

$$m = \frac{0.0075}{F + 5.357}$$

Finally, introducing this term into equation (54) and reducing, the following equations for the apparatus when the Leyden jar with the chain connection was used, result:

$$S = \frac{\left(0.821 - \frac{3.965}{F + 5.357}\right) \sqrt{F + 0.6}.}{0.002155} \tag{56}$$

$$Q = \left(0.821 - \frac{3.965}{F + 5\,357}\right) \sqrt{F + 0.6}. \tag{57}$$

A comparison of the indications of equation (56) with the observations is exhibited in the table on page 187, and also shown to the eye on Plate XXI. The accordance is so close as to give confidence in the success of this analysis, which, as will appear hereafter, is fully borne out by comparative fuze tests with this and the other condensers.

This terminates the discussion of the constants of my fuze-testing electrometer; and when it is remembered that many of the charges employed in deducing them were so small as to be quite inappreciable to the sense of touch, the study furnishes a beautiful illustration of the precision of the modern system of electrical measurement, rendered possible by the invention of Sir William Thomson's reflecting galvanometer. My apparatus proved to be by no means too delicate; for its most careful adjustments were needed in testing the large class of dangerously sensitive fuzes, now fortunately banished from our market, in part through its agency.

Theory of Ignition.—The theory usually accepted for the ignition of high tension and medium tension fuzes is that the heat generated by the passage of the spark through the priming raises the temperature sufficiently to produce explosion. This view rests entirely upon analogy, no attempt having been made to verify it by experimental research; indeed, without suitable apparatus specially designed for the purpose no precise analysis of the problem would be possible.

Some classes of these fuzes are so excessively sensitive to electrical disturbance that, for them at least, it is not easy to accept this theory. A person placed in the same circuit experiences no sensible shock from charges greatly exceeding the minimum required to explode them. An ebonite comb passed a few times through the hair of a child holding one of the terminal wires, the other being insulated in the air, generates a current quite sufficient to fire the priming On one occasion at Willets Point (July 15, 1871) fifty of these fuzes connected in series were hung upon nails driven in the sides of a wooden shed, and the induction of an ordinary thunder cloud caused the explosion of five of them—every fuze which touched a nail.

It seemed desirable to study experimentally the probable explanation of ignitions due to so slight apparent disturbances of electrical equilibrium, and more generally to investigate the laws governing the explosion of the two classes of fuzes now under consideration.

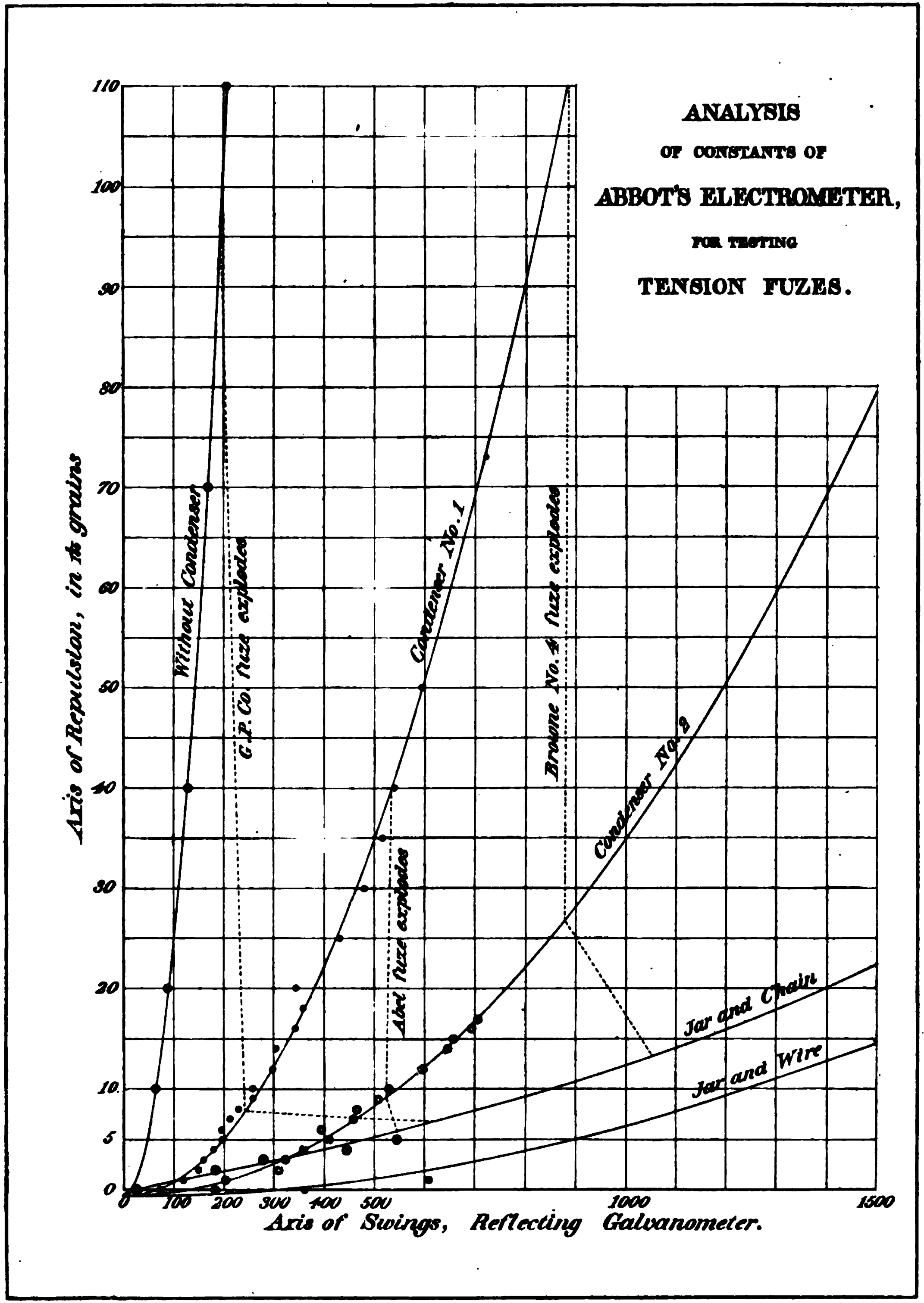
As already seen the apparatus described above renders it easy to measure both the quantity of electricity, Q, and the corresponding difference of potential, P, which cause the explosion of a tension fuze; and also, by changing the condenser, to determine the effect of varying the numerical value of the potential factor. But Joule's law for the heat (H) generated by a current of electricity, of which the electromotive force is E, and the strength is C, traversing a circuit of which the resistance is R, in the time T, is:

$$H = C^2RT = QCR = QE = QP.$$

Hence, if the theory that the explosion is due directly to the rise in temperature caused by the heat developed by the passage of the spark be true, we must have the product QP nearly constant with different condensers.

Experiments were made to supply data for applying this test. Before considering them, however, it may be well to invite attention to one important difference between medium and high-tension fuzes. The former oppose so small a resistance to the passage of the spark that a relatively small difference of potential may safely be assumed to be sufficient to force the charge through the priming. With high-tension fuzes, which oppose an enormous resistance, no such assumption is legitimate. Their primings constitute an absolute break of continuity in the circuit. This difference between the two classes is indicated to the eye by the electroscope used with my electrometer With medium-tension fuzes and small potentials, the balls drop instantly; with high-tension fuzes, up to a certain point, they fall gradually. Hence, with the latter class it is absolutely necessary to create a difference of potential sufficient to force the spark through the priming before explosion *can* occur. With a large condenser this may imply a charge *larger than is absolutely needful to cause explosion;* and hence, for them the minimum charge can only be determined by using a small condenser with its relatively large difference of potential; in other words, it is necessary with high-tension fuzes that the factor P in the product $(K + K_{,}) P = Q$ shall be large enough to force the charge through the priming before it can be considered certain that the minimum exploding charge has been determined.

Bearing this principle in mind, three different fuzes were selected for the trial—the Abel magnet fuze, as a fair sample of the medium-tension class (resistance about 100,000 ohms when measured with six Leclanché cells); the Giant Powder Company fuze, as the representative of a rather sensitive high-tension variety (resistance exceeding ten megohms); and the Browne No. IV, as a good type of a safe high-tension fuze (resistance similar to last). The following table exhibits a summary of the results, each figure being the mean of from ten to twenty independent measurements which accorded well with each other:



ANALYSIS
OF CONSTANTS OF
ABBOT'S ELECTROMETER,
FOR TESTING
TENSION FUZES.

The Heliotype Printing Co 211 Tremont St Boston

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Tension fuzes.

CONDITIONS OF IGNITION.

Fuzes tested.	Without condenser.				With condenser No. 1.				With condenser No. 2.				With jar and chain.			
	Failed.		Exploded.		Failed:		Exploded.		Failed.		Exploded.		Failed.		Exploded.	
	Q.	P.	Q.	P.	Q.	P.	Q.	P.	Q.	P.	Q.	P.	Q.	P.	Q.	P.
	Mf.	*Volts.*	*Mf.*	*Volts.*	*Mf.*	*Volts.*	*Mf.*	*Volts.*	*Mf.*	*Volts.*	*Mf.*	*Volts.*	*Mf.*	*Volts.*	*Mf.*	*Volts.*
Abel:																
1874........	....	.....	....	.....	....	.....	....	.....	1.36	1,847	1.42	1,917	1.11	1,317	1.28	1,422
1879........	....	....	....	.....	0.99	2,976	1.14	3,411	1.07	1,444	1.23	1,671	0.87	1,163	1.17	1,376
Means...	....	.....	....	... .	0.99	2,976	1.14	3,411	1.22	1,645	1.33	1,794	0.99	1,240	1.22	1,399
G. P. Co.																
1879........	0.35	2,274	0.38	2,468	0.46	1,372	0.52	1,551	1.00	1,354	1.10	1,482	1.15	1,321	1.33	1,444
B. No. IV:																
1874........	....	.....	....	.....	....	.....	....	.....	1.79	2,446	1.87	2,542	2.24	1,984	2.36	2,057
1874........	....	.....	....	.....	1.92	5,756	2.02	5,989	....	.....	....	.....	2.25	1,992	2.37	2,063
1874........	....	.....	...	.....	1.62	4,833	1.69	5,066	1.95	2,771	2.01	2,873	....	.....	....	.....
1879........	....	.....	....	.....	1.91	5,106	1.98	5,260	2.16	2,930	2.32	3,146	1.77	1,712	2.07	1,880
Means...	....	.....	....	.....	1.82	5,232	1.90	5,438	1.97	2,716	2.07	2,854	2.09	1,896	2.27	2,000

To exhibit these comparisons graphically they have been translated into swings of the beam of light by the foregoing formulæ, and plotted in dotted lines on Plate XXI. For example, to explode the Abel fuze required 0.39 grains of repulsion with condenser No. 1; 0.09, with condenser No. 2; and 0.06, with the jar and chain, the corresponding swings with the galvanometer being in each case about 530 divisions.

Considering first the Abel fuze, which, since the question of potential can be ignored, appears the most simple standard of comparison, these figures prove beyond cavil that the ignition depends upon the quantity and not upon the product of the quantity by the difference of potential. Thus, for the grand mean, although the potential factor in the expression $(K + K_{,})$ P varied between 3,411 and 1,399 volts, the fuze always exploded when 1.25 ± 0.03 microfarads of electricity traversed the priming. Hence, since the second introduction of P as a multiplier would produce great discrepancies in the results shown by the three condensers, which without it are very accordant, the explosion *is not due directly to the rise in temperature caused by the heat generated by the passage of the spark, but to some other cause.*

The same conclusion, although at first sight less apparent, is reached by an analysis of the results with the other varieties.

Thus, the Giant Powder Company fuze, without a condenser, is exploded by the passage of a charge of 0.38 microfarads, with a difference of potential of 2,468 volts, failing with 0.35 microfarads and 2,274 volts. With condensers No. 1 and No. 2 and the Leyden jar, charges of 0.46 and 1.00 and 1.15 microfarads fail, because the corresponding differences of potential (1,372 and 1,354 and 1,321 volts) are too low to force the charge through the priming. As soon as this difference reaches about 1,450 volts, the charge passes and the explosion, with the condensers, results *from an excessive* *charge.* Hence, the true minimum charge for this fuze is, say, 0.4 microfarad, but it cannot be fired with a difference of potential under about 1,450 volts.

In the Browne No. IV fuze, the break between the wire terminals in the priming chamber is considerably larger than in the Giant Powder Company fuze, and a difference of potential of about 2,000 volts is apparently needful to force the charge through the priming. The quantity required with the three condensers is 1.90, 2.07, and 2.27 microfarads, respectively, with corresponding differences of potential of 5,438, 2,854, and 2,000 volts. Evidently the minimum explosive charges, here also, are nearly proportional to the *quantity of electricity traversing the priming*, a small allowance being made for the modifying cause indicated above.

It will be noted that neither for medium nor high tension fuzes do the figures indicating ignition suggest any law based upon the product of the quantity by the difference of potential. On the contrary, they all imply that the ignition depends simply upon the *quantity of electricity traversing the priming.*

In fine, these experimental researches all seem to indicate that rise in temperature induced by the passage of the spark is not the true cause of the explosion of the primings of high and medium tension fuzes—at least, if we may assume that this rise is proportional to the heat developed (QP). Even if this assumption be challenged the difficulty is not met, for the advocate of the usual theory, in that case, must be prepared to admit that this rise is proportional to $\frac{H}{P}$, a law for which we have no warrant either from theory or from analogy.

In my judgment, these researches force us to seek the cause of the ignition in some occult law of molecular physics, and the following naturally suggests itself. May not the spark *polarize the planes* of the molecular orbits, as well as increase their amplitude? Professor Henry, many years ago, proved that the passage of a spark of electricity among steel needles caused their permanent magnetization, which, by the theory of Ampère, would imply an analogous effect. In compounds, where the chemical equilibrium is so unstable as in these primings, such a cause might well induce chemical action involving new combinations of the atoms, attended with explosion, or perhaps with a rise in temperature ample of itself alone to explain the phenomenon.

Since high tension fuzes require a spark for their ignition, this discussion covers the whole ground for them. Medium tension fuzes, however, may also be fired by the passage of a voltaic current through their priming, and this mode of ignition has been treated by Major Malcolm, R. E., in a very interesting paper read before the Society of Telegraph Engineers, in London, on May 13, 1874.

Major Malcolm discovered, by experiment, that a marked fall in resistance precedes explosion when caused by the passage of a voltaic current. He suggested that this change might continue with great rapidity during the instant just before ignition (in which it could not be followed by his instruments), and might thus explain the explosion by the heat generated by a current much stronger than the normal resistance of the fuze would imply.

This case is entirely different from ignition by a spark, and Major Malcolm's theory seems to me to be not only consistent with all the known facts, but also to receive confirmation from more recent investigations leading to the discovery of the microphone. With a voltaic or a continuous magneto-electric current the element of time, which is inappreciable with the spark, becomes very important, and it is not hard to understand how a gradual and increasing rise in temperature quite sufficient to produce ignition may be brought about. In fact, the Beardslee fuze, which cannot be fired by any ordinary frictional spark, and the Abel fuze, after it has deteriorated sufficiently to reach the same condition, may often be exploded by a strong voltaic or magneto-electric current.

Standard of Safety.—As already stated, many varieties of tension fuzes are so sensitive to electrical disturbance as to be criminally dangerous for practical use. Having adopted a system of measurement by which these fuzes could be accurately classified as to sensitiveness, the next point was to decide upon an absolute standard of safety.

Whatever changes may be occurring in the electrical condition of bodies around us, we know by experience that none appreciable to our sense of touch are to be apprehended, under ordinary conditions. Hence, if no fuze which can be fired by a charge too small to be detected by this sense be employed, the condition of reasonable safety may be regarded as fulfilled. On the other hand, this limit should not be largely exceeded; because it is often desirable to fire several charges simultaneously, and if the fuzes be too hard to ignite, miss-fires with loss of time and dangerous manipulations are sure to occur.

To fix the numerical value of this standard, a man holding the wire terminals in his moistened hands replaced the fuze in the electrometer circuit, and the reading corresponding to the smallest sensible shock was noted. Some individuals proved to be more sensitive than others, but the following record may be considered a fair average:

Without a condenser, a shock corresponding to a reading of 180 could not be felt; with condenser No. 1, a reading of 8 could not be felt, and of 10 could be just detected; with condenser No. 2, these numbers were 2 and 3, respectively. Translated into microfarads, these results may be tabulated as follows:

Without a condenser,	0.52 mf. could not be felt;	
With condenser No. 1,	0.64 mf. could not be felt;	0.75 mf. could be just detected.
With condenser No. 2,	0.53 mf. could not be felt;	0.58 mf. could be just detected.
Means,	0.56	0.67

From these figures, it appears that no fuze which can be fired with a less charge than about seven-tenths of a microfarad can be regarded as a safe fuze. Eight-tenths of a microfarad is distinctly felt by any person, and this was adopted as the minimum limit. As to a maximum limit, a thoroughly good fuze, not liable to deteriorate by age and exposure to dampness, and which requires about 2 microfarads for ignition, was discovered; and this charge was accordingly adopted. It gives a decided but not disagreeable shock. The charges required for igniting the different primings subjected to trial have ranged between 0 03 and 16.00 microfarads.

It only remains to consider the several fuzes, and the results obtained by testing them in the manner explained above. Tests made prior to October 25, 1872, are not usually discussed in the text, because the apparatus had not been perfected until that date.

The Abel Magnet Fuze—Medium Tension.—This fuze was devised by Professor Abel, in 1858, specially for use with magneto-electric apparatus. He had in view the explosion of several fuzes simultaneously, and modified his priming accordingly, so that after ignition no conducting residue should remain between the terminals in the priming chamber. His fuze when newly made has a high reputation for uniformity and certainty of action; but if kept long on hand it is liable to become uncertain when used with electricity of high potential.

Ladd, of London, is the authorized maker; and attempts by other parties in this country and Europe to reproduce this priming have been by no means successful, as will be shown hereafter. Ladd manufactures four patterns of this fuze—*Experimental*, for laboratory trials; *Gunpowder*, designed for igniting charges of gunpowder; *Cannon*, for use with cannon; and *Gun-cotton*, for explosive compounds which require a powerful detonator to develop their full force. They differ only in external form and in the firing charge, which in the first pattern is entirely omitted; in the second and third, consists of gunpowder; and in the last, of fulminating mercury. The break filled by the priming is uniformly $\frac{1}{16}$ of an inch.

This celebrated priming consists of:

	Parts.
Sub-phosphide of copper	10
Sub-sulphide of copper	45
Chlorate of potassa	15

The materials are reduced separately to the finest possible state of division, moistened by alcohol, and rubbed well together in a mortar. The mixture is then carefully dried, and preserved in closed vessels until required.

The ingredient first named is the igniting agent; the potassium chlorate supplies the oxygen; and the sub-sulphide of copper gives the requisite degree of conductivity.

The largest number of these fuzes which it was attempted to fire together on one wire on land, in the original trials at Chatham, was twenty-five; they were connected in derived circuit, the earth forming the return. An appreciable interval between the explosions could be detected by the ear with this number, but hardly with twelve. The distance to the apparatus (Wheatstone's magnetic exploder) was about 600 yards. Under water, not more than four simultaneous explosions could be depended upon, because the circuits caused by wetting the terminals of the fuzes which exploded first prevented the rest from receiving the requisite current.

A supply of these fuzes was early obtained from Ladd, and they have been carefully tested from time to time, both for sensitiveness and for permanence, as is shown by the following summary. Imitations made by Ruhmkorff, of Paris; Smith, of Boston; and Mowbray, of North Adams, Mass., have also been tested, but with results far less satisfactory than those obtained from the original. The difficulty is believed to lie in the manner of preparing the sub-phosphide of copper, which Professor Abel has not specified.

It will be noticed that none of these fuzes were imported after 1872. Since that date, the proportions of the ingredients have been varied to effect different objects; but, it is understood, without materially changing the character of the fuze.

The Abel magnet fuze.

ELECTROMETER TESTS.

Maker.	Date.		Number tested.		Igniting charge—normal state.			Remarks.
	Made.	Tested.	Total.	Normal state.	Least.	Greatest.	Mean.	
					Mf.	*Mf.*	*Mf.*	
Ladd	May, 1871	August, 1871	19	19	1.12	2.00	1.35	
	....do	September, 1872	5	5	1.04	1.08	1.07	
	....do	October, 1872....	10	9	0.99	2.00	1.04	One required 4.5 microfarads.
	....do	February, 1873 ..	7	5	1.04	2.47	1.58	One failed, 14 microfarads; one required 5 microfarads.
	....do	March, 1879	25	13	0.66	2.35	1.28	Several failed with 8 microfarads.
	April, 1872	October, 1872....	5	4	1.97	2.35	2.14	One required 5 microfarads.
	.. do	March, 1874	10	10	1.23	1.61	1.42	
	....do	....do	7	7	1.21	1.38	1.28	
	....do	April, 1874	3	2	1.28	1.40	1.34	
	....do	February, 1875 ..	8	7	0.85	0.99	0.88	One failed, Smith machine.
	....do	March, 1875	6	5	0.66	1.21	0.81	One required 40 Leclanché cells.
	....do	April, 1875	6	6	0.73	0.85	0.77	
	....do	January, 1876 ...	10	10	1.51	1.84	1.70	
	....do	May, 1876	4	4	1.61	1.71	1.66	
	....do	April, 1877	15	11	1.02	1.97	1.18	Two required Smith machine.
	....do	... do	16	12	0.91	1.40	1.14	One failed, Smith machine.
	....do	March, 1879	6	4	1.38	2.11	1.56	Two required 4 microfarads.
	....do	....do	18	10	1.04	1.88	1.23	Seven required from 3 to 9 microfarads.
	....do	....do	38	13	0.99	1.28	1.14	No tests above 4 microfarads.
	....do	....do	24	10	1.16	1.46	1.25	Do.
Summary...	....	....	242	166	0.66	2.47	1.23	
Ruhmkorff..	April, 1875	January, 1876 ...	10	8	1.80	4.35	2.65	One failed, Smith machine.
	....do	May, 1879	15	7	1.29	11.12	4.04	Eight failed with 13 microfarads.
Smith.......	July, 1871	July, 1871	24	23	2.52	10.75	5.21	One required Smith machine.
	....do	May, 1879	14	10	3.33	14.53	8.75	Four failed with 15 microfarads.
Mowbray...	....do	September, 1872.	4	4	7.41	10.42	8.38	
	....do	May, 1879	25	4	6.57	15.57	12.48	Twenty-one failed with 16 microfarads.

This table requires considerable explanation. The priming as made by Ladd is remarkably uniform when first received, requiring an igniting charge varying but little from 1.2 microfarads. This constitutes a safe and sure fuze. Storage for one or two years, at least in a damp climate like that of Willets Point, induces a marked loss of sensitiveness in individual fuzes; and this continues to increase, until after a lapse of seven or eight years the priming has become so uncertain as to be entirely untrustworthy for use with frictional apparatus. Some individual fuzes cannot then be ignited by a 3-inch spark from a powerful Smith machine, while others show no change whatever from their normal state. But even in this deteriorated condition most of them can be ignited on short circuit by a battery of 100 Leclanché cells, or by a large Wheatstone magnetic exploder, probably by the heat developed by the continued current. It may be added that, after long storage, frequent failures of the gun-cotton pattern have occurred in actually firing torpedoes at Willets Point, both with Smith's frictional machine and with Farmer's powerful dynamo-machine.

The table has been arranged with a view to exhibit the progress of this deterioration Under the heading of "normal state" are classed all Ladd's fuzes which required less than 3 microfarads for ignition, and a comparison of the number of such fuzes with the total number tested on any date will give the information sought.

In a paper read before the Society of Telegraph Engineers on May 13, 1874, Professor Abel explains that his priming is liable to deteriorate if exposed to dampness, and states that its composition is permanent if kept absolutely dry. The foregoing tests were made with the regular gunpowder or gun-cotton patterns, and care was observed to store them in a dry room. If dampness be the cause of their deterioration, it can only be charged to faulty mechanical details in the adopted form of construction, which certainly seems open to criticism.

As to the French and American imitations but little need be said. None of them are sufficiently sensitive for practical use. They all exhibit the tendency to deteriorate from long storage, but only those which could not conveniently be fired by the usual testing apparatus are entered as abnormal in the table, because even at first they were too uncertain to justify a closer classification.

It should be mentioned that while Ruhmkorff and Smith call their primings by the name of Professor Abel, Mowbray has somewhat modified the composition. On July 27, 1869, he took out a pattern for an improved method of exploding nitroglycerine, and in it adopted the Abel priming exactly. In the succeeding November he patented the following modification, which is what was tested. The copper is replaced by silver, and sulphide of mercury is added, giving:

	Parts.
Phosphorus	5
Sulphur	15
Silver	100
Mercury	25
Potassium chlorate	30

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The electrical resistance of all these fuzes varies between wide limits. Different results, of course, are obtained by varying the battery power, and I have usually employed six small Leclanché cells (internal resistance per cell about 10 ohms) in the measurements. If long continued this current will often cause explosion. Ladd fuzes show an average resistance of about one-tenth of a megohm, ranging from 10 megohms to a few hundred ohms Smith's priming is similar to Ladd's in this respect, but the other two usually exceed 10 megohms.

Although careful tests have been made, no connection between the resistance of fuzes charged with the Abel priming and their sensitiveness to frictional electricity has been detected.

It will be remembered that this well-known fuze was designed for use with magneto-electric apparatus, for which it is generally admitted to be well suited, especially when newly made, and above all when used in dry climates. The foregoing tests with frictional electricity have certainly developed the serious defect of want of permanence, which places the priming below several of its competitors in practical value.

The Abel Submarine Fuze—Medium Tension.—The Abel magnet fuze, both as originally devised and as recently modified by varying the proportions of the component parts, is liable to the objection that it will accidentally explode if subjected to the continued action even of a weak testing battery. To meet this defect, which is a very serious one in submarine mining, Professor Abel has devised a new composition, consisting of an intimate mixture of powdered graphite and fulminating mercury. This mixture is compressed into the cavity containing the wire terminals until the desired resistance is obtained, which may easily be ascertained by keeping a feeble current passing through the priming, with a galvanometer in circuit.

The following extract from the address of Professor Abel, as president of the Society of Telegraph Engineers, delivered on January 24, 1877, gives interesting facts respecting this fuze:

"In a paper contributed to the society by one of its more promiment members, Lieutenant-Colonel Stotherd, R. E, on electric fuzes, that officer pointed out that certain defects in point of permanence, and certain difficulties connected with the electrical testing of the 'phosphide' high-tension fuze known by my name, had led me to construct another form of high-tension fuze specially for submarine mining service. In this, the conducting and igniting composition or bridge which connects. the poles consists of a very intimate mixture of graphite and mercuric-fulminate, two substances concerning whose freedom from liability to oxidation by atmospheric influence, and otherwise permanent characters, no doubt could be entertained. The poles of this fuze, like those of the older one, consisted of two fine copper wires, arranged parallel and embedded at a distance of 0.05 inch apart in an insulating column, which, in the

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new fuze, consists of a mixture of Portland cement, with sufficient sulphur to allow of its being melted and cast in a mold, producing a very rigid support, upon which the priming composition can be consolidated over the slightly projecting terminals of the copper wires or poles by the application of considerable pressure, the electrical resistance of the fuze being regulated by the degree of compression of the composition. This cast column or insulating support of cement was adopted in place of the gutta-percha used in the old fuze, because the want of rigidity in the latter material did not permit of the attainment of uniform and permanent compression of the priming composition. This so-called 'submarine fuze' having furnished very satisfactory results, a number were supplied to different military stations for submarine mining service, but, after a considerable time had elapsed, many of them were found to have fallen very greatly in resistance; thus, the average resistance of the fuzes being 15,000 ohms, many were found to have only a resistance of 300 or 400 ohms, and one or two had fallen even below 50 ohms. The careful dissection and examination of these fuzes afforded at first no clue whatever to the cause of this change. The graphite-fulminate mixture appeared unaltered in compactness and was unchanged in composition; and, on being removed from the altered fuzes and applied as priming material in new fuzes, the resistances of these was the same as if new composition had been employed. Mr. E. O. Brown, a member of this society, who has done good work in applied electricity, was deputed by me to unravel this mystery, and soon fathomed it. An examination of the interior of the small pillars of cement, which appeared from the exterior perfectly solid throughout, revealed the existence in many of them of very minute hair-line cracks or fissures, extending sometimes right across the space between the inclosed small copper wires, and evidently caused by unequal contraction of the wires and the cement when the latter had been cast around the former. These minute fissures would of themselves not have effected the electrical character of the fuzes, but the surfaces of many of them were observed to be dark colored, and this coloration proved to be due to sulphide of copper. The penetration of air, and with it the ever concomitant moisture, to the interior of these little columns, established, in course of time, chemical action between the sulphur in the cement, the copper surfaces, and the atmospheric oxygen; the resulting sulphate of copper was slowly conveyed by the moisture and the capillary action of the minute cracks along these on either side, becoming afterwards reduced by the sulphur in the cement to sulphide, with which the fissures became coated until it formed one or more complete bridges between the copper poles. Thus, the high-resistance bridge, or the fuze proper, was in course of time completely cut out of circuit by the formation of one or more very perfect, though minute Statham fuzes, of comparatively high conducting power, in the head of the fuze itself. Chemical knowledge, having been instrumental in discovering this unsuspected source of failure, at once provided the remedy; five wires of platinum, upon which the sulphur, aided by air and moisture, has no action, were substituted for those of copper, and the permanence of the fuze was secured."

This fuze has been adopted by the Royal Engineers for the submarine service of Great Britain, and is highly commended by Major Stotherd and others. The standard resistance is about 15,000 ohms when tested by a couple of Daniell cells; but it is liable to change when subjected to the long-continued action even of a weak voltaic current. Two fuzes in derived circuit are always used in the torpedo.

Although this fuze is specially designed for a powerful voltaic battery, it may also be used with frictional electricy; and accordingly it has been tested to determine its value with this class of apparatus.

Two small samples were procured at different dates from Ladd, but the high and variable resistances which they exhibited sufficiently proved that he did not devote as much attention to making them uniform in this respect as is regarded desirable by the British Government. Moreover, the precise percentage of graphite was not reported either by him, or by Mr. Abel and the officers of the Royal Engineers, in their published statements.

At one time during the investigations conducted at Willets Point it appeared important to discover a priming which, with a low resistance, should combine a suitable degree of sensitiveness to frictional electricity. Accordingly a few experimental fuzes were made to develop the character of this priming, and with satisfactory results, as appears from the following table. Plumbago was used as the conducting ingredient, and no special attention was paid to securing uniformity of resistance, as this point was not important in the use for which the fuze was desired. Six compositions were tested, viz:

Experimental priming A ; 90 parts fulminating mercury and 10 parts plumbago, dry.
Experimental priming A'; same, compacted with alcohol.
Experimental priming B ; 80 parts fulminating mercury and 20 parts plumbago, dry.
Experimental priming B'; same, compacted with alcohol.
Experimental priming C ; 60 parts fulminating mercury and 40 parts plumbago, dry.
Experimental priming D ; 40 parts fulminating mercury and 60 parts plumbago, dry.

The following table exhibits a summary of the electrometer tests of Ladd's fuzes and of these several primings. It will be noticed that the former, made at different dates, varied considerably among themselves, and that some of them were dangerously sensitive to frictional electricity; that the compacting in alcohol had a very marked effect in reducing the resistance and increasing the sensitiveness; and that although it was possible to secure any desired resistance, when this was made *very small* the priming was not sufficiently sensitive for practical use:

The Abel submarine fuze.

ELECTROMETER TESTS

Maker.	Date.		Number tested.	Resistance in ohms.			Igniting charge in microfarads.		
	Made.	Tested.		Least.	Greatest.	Mean.	Least.	Greatest.	Mean.
Ladd	April, 1872	March, 1875	2	300,000	3,000,000	1,650,000	0.66	1.21	0.94
	September, 1875.	....do	8	76,000	9,000,000	2,317,000	0.06	0.85	0.40
	....do	April, 1875	5	....	....	....	0.23	0.46	0.31
	....do	May, 1879	30	16,400	1,490,000	149,366	0.64	7.19	2.72
Experimental, A	March, 1875.....	March, 1875	10	10,000,000	10,000,000	10,000,000	1.54	2.47	2.00
Experimental, A′	....do	April, 1875	10	500,000	10,000,000	8,850,000	0.45	1.38	0.89
Experimental, B	....do	March, 1875	10	27,100	10,000,000	5,850,948	2.35	3.40	2.79
Experimental, B′	... do	April, 1875	27	240	5,000	1,369	0.14	1.71	0.85
Experimental, C	....do	March, 1875	11	77	470	242	3.92	9.42	6.47
Experimental, D	.. do	....do	10	7	390	113	5.33	9.78	7.65

In fine, this table sufficiently proves that it would not be hard by continuing the study of this priming to arrive at a medium-tension fuze, of comparatively low resistance, which should possess a suitable degree of sensitiveness to frictional electricity, while the ingredients of the composition warrant a belief in its permanency. This would have been attempted had not the general progress of the investigation rendered such a fuze unnecessary for our submarine mines. It may be added that out of the whole number tested with the electrometer, none failed to explode, and that among individual fuzes charged with the same composition no law connecting resistance and sensitiveness was apparent.

The von Ebner Fuze—Medium Tension.—This fuze was devised by General von Ebner, of the Austrian Engineers, for use with frictional electricity, and was exhibited at the Paris Exposition of 1867. It has been much employed in blasting upon the Continent of Europe, where, with various modifications, it is the principal competitor of the Abel fuze. Together they have superseded the Statham fuze, the first practically used with electricity of high potential, and which was introduced about the year 1840. The von Ebner fuze is but little known in this country.

The composition is a modification of that used in ordinary friction primers for cannon (2 parts of sulphuret of antimony and 1 part potassium chlorate), being composed of equal parts of sulphuret of antimony and potassium chlorate, with sometimes the addition of powdered plumbago to give conductivity. One formula of von Ebner is the following, the ingredients being intimately mixed:

	Parts.
Sulphuret of antimony	44
Chlorate of potassa	44
Plumbago	12

The plumbago is also sometimes applied in the form of a mark drawn between the wire terminals, and sometimes it is entirely omitted. The latter modification constitutes the present form of the Gaiffe and Compte fuze.

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The Champion, Pellet, and Grenier priming is another modification of that of von Ebner, the conducting material being horn carbon, and 22 parts being used instead of 12 parts, as in the above formula. Their composition is also ground with alcohol, thus dissolving the potassium chlorate, which, in subsequently crystallizing, forms the whole into a solid mass that may readily be exploded by a powerful voltaic battery, as well as by electricity of high potential.

Samples of the von Ebner fuze (percentage of ingredients not stated) were procured from Digney Frères et Cie., from Ruhmkorff and from Gaiffe; and certain modifications of the priming were prepared for special study in connection with our investigations in submarine mining. These modifications were:

Experimental priming E; sulphuret of antimony 40 parts, chlorate of potassa 50 parts, horn carbon 10 parts.
Experimental priming F; sulphuret of antimony 38 parts, chlorate of potassa 57 parts, horn carbon 5 parts.
Experimental priming G; sulphuret of antimony 47 parts, chlorate of potassa 47 parts, horn carbon 6 parts.
Experimental priming H; sulphuret of antimony 46 parts, chlorate of potassa 48 parts, horn carbon 6 parts.

The following table exhibits a summary of the results of the test, the details being given in full in Appendix B:

The von Ebner fuze.

ELECTROMETER TESTS.

Maker.	Date.		Number tested.		Igniting charge in microfarads.			Remarks.
	Made.	Tested.	Total.	Good.	Least.	Greatest.	Mean.	
Digney	September, 1873.	February, 1874	1	1	1.04	1.04	1.04	
Ruhmkorff	April, 1875	January, 1876	13	11	0.29	0.94	0.43	Two failed at 2 and 4 microfarads.
Do	do	April, 1879	20	18	0.38	4.44	1.69	Two required 9 and 12 microfarads.
Gaiffe	June, 1880	October, 1880	40	34	0.42	3.55	2.06	Three required 7 microfarads and 3 failed.
Experimental priming E	January, 1876	January, 1876	14	10	1.29	3.33	1.80	Four failed with Smith machine.
Experimental priming F	do	do	12	11	1.16	2.19	1.59	One failed with Smith machine.
Experimental priming G	do	do	10	10	1.71	3.08	2.17	
Experimental priming H	do	do	23	20	0.64	2.52	1.22	Three failed with Smith machine.

The number of these experiments is not sufficient to warrant any very definite conclusions as to the von Ebner priming, but they indicate that individual fuzes, even when in good condition, are liable to explode with charges too small to be regarded as entirely safe; that long storage produces a marked reduction in sensitiveness; and, in fine, they tend to confirm the suspicion with which any priming containing potassium chlorate is regarded by most experts in this country. The numerous failures in our cannon primers, usually attributed to moisture absorbed by this salt, are well known; and, as already seen, the Abel magnet fuze, which contains it, exhibits the same defect. There is a strong tendency in America to avoid this ingredient in preparing electrical fuzes.

The resistance of the von Ebner priming varies within wide limits—ranging, in the fuzes tested above, between ten megohms and 4,000 ohms. Indeed, some of Gaiffe's fuzes had only a few hundred ohms.

Other European Fuzes—Medium and High Tension.—In addition to the French fuzes already mentioned, samples were procured from Digney Frères et Cie. and from the Société Général pour la Fabrication de la Dynamite, of Paris, but the composition of the primings was not stated. The mechanical details adopted by these makers seem open to criticism.

Four different samples were received from Digney Frères et Cie., all belonging to the high-tension class (resistance 10 megohms). Of the first sample, eight out of nine fuzes failed to explode with about 13 microfarads, and the other required 10.83 microfarads. Of the second sample, which was marked "préferees par le genie," four out of five fuzes failed in like manner, and the other required 4.84 microfarads. Of the third sample, three out of nine fuzes failed in like manner; and the rest exploded with a mean charge of 4.13 microfarads, ranging from 0.29 to 10.83 microfarads. The fourth sample was better. Eight fuzes were tested and they all exploded; the mean charge being 2.55, and the extremes 1.41 and 3.54 microfarads.

The fuze of the Dynamite Company varied from 170,000 ohms to 90 ohms in resistance, and could hardly be fired with less than about 13 microfarads. It seems better suited for a voltaic battery or a powerful magneto-electric machine than for frictional apparatus.

The fuze for electricity of high potential most in use in Prussia is essentially that of von Ebner, the only difference being in details of construction.

In Belgium, both the von Ebner and the Abel primings are employed, and also a picrate powder of which the exact composition is not made public.

In fine, for fuzes of the classes now under consideration, the von Ebner and Abel primings, with local modifications, may safely be considered the favorites in Europe.

The Beardslee Fuze—Medium Tension.—This is the first original American fuze that has played any important part in this country. It was devised during the late civil war by Capt. F. E. Beardslee, for use with the magneto-electric machine invented by his father—which was largely employed in operating the field telegraph system and the naval torpedoes of the Union. The fuze was first publicly tested in February, 1863, in the defences of Washington.

The wire terminals of the circuit are flush with the face of a connecting wooden plug, and are only separated from each other by a small groove made by a file. In this groove a soft pencil is drawn several times back and forth, making a black lead

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bridge for the current. A paper cylinder round the plug forms a receptacle for the priming, which consists of mealed powder next the bridge, with Dupont's fine rifle powder resting upon it as a bursting charge. In mechanical details, the fuze is susceptible of great improvements; but in principle it forms a safe and serviceable mode of ignition with certain kinds of electrical apparatus, and one which is easily improvised.

Although this was the electrical fuze almost exclusively used by the Union forces during the late war, it has never been much employed on the civil works of the country—chiefly, perhaps, on account of the high price demanded (50 cents each). It has been entirely out of the market for many years.

From the simple construction of this fuze, it is certain that the ignition is caused by the rise in temperature produced by the passage of the current through the black lead bridge; and hence that time is an important element, especially near the minimum limit of heating power. Moreover, as from the nature of the bridge the resistance must vary between wide limits, the question of electromotive force cannot be ignored in selecting a suitable machine for firing.

Experiment proves that this fuze is entirely unsuited for any variety of frictional apparatus. Charges of 10 microfarads and upwards with my electrometer uniformly failed to explode it, and the same was true with the much more powerful charges used practically in blasting—say an inch spark from a large condenser. Nevertheless, the small single discharge from a Breguet or Marcus magneto-electric machine, which when received as a shock is hardly disagreeable, rarely fails to ignite the priming!

An ordinary firing battery, like that used in the Torpedo Service, instantly explodes the fuze; but the minimum limit as to the number of cells required was not determined.

It is claimed that with Beardslee's magneto-electric machine, this fuze has been fired over 200 miles of ordinary telegraph wire (line between New York and Washington); and single fuzes may be regarded as certain to explode through the leading wires usual in blasting. Failures with a dozen or fifteen fuzes, connected in derived circuit, are exceedingly rare.

In regard to other portable magneto-electric apparatus, those developing sufficient differences of potential to give smart shocks, will usually fire the fuze; but those designed to give a current of considerable strength, but of low electromotive force, usually fail.

The following table of tests with single fuzes of measured resistance is added to illustrate these points. The machines will be found discussed in the next chapter; the actual order of trial is preserved in the text; the machines which caused ignition are printed in italics, the others failing.

Resistance, 32,000 ohms: 100 *Leclanché cells*, in series.

Resistance, 13,090 ohms: *Jürgensen.*

Resistance, 10,760 ohms: Mowbray (frictional); Wheatstone; Jürgensen; Marcus; Breguet; *Siemen's spark.*
Resistance, 9,500 ohms: Mowbray (frictional); *Breguet.*
Resistance, 7,720 ohms: *Jürgensen.*
Resistance, 7,236 ohms: 34 *large Smee cells,* in series, a less number failing.
Resistance, 6,690 ohms: *Siemen's spark.*
Resistance, 6,325 ohms: Laflin & Rand; Siemen's current; Hochhausen; Gramme; Smith (dynamo); *Marcus.*
Resistance, 3,862 ohms: 20 *large Smee cells,* less failing.
Resistance, 3,900 ohms: 55 *large Smee cells,* less failing.
Resistance, 2,584 ohms: *Farmer.*
Resistance, 2,424 ohms: *Wheatstone.*
Resistance, 1,325 ohms: Gramme; *Marcus.*
Resistance, 312 ohms: Mowbray (frictional); *Breguet.*

A modification of this fuze is supplied by the London Ordnance Works, devised by C. A. McEvoy, who, after the war, and before going to England, had been associated with George W. Beardslee in this country. He uses a mixture of plaster of Paris, powdered glass, and melted sulphur for his plugs, and connects the inner terminals of his wires by a black lead-pencil mark, which is subsequently scratched across with a needle point to give a small break for the spark. His priming is that used in ordinary cannon primers (2 parts sulphuret of antimony and 1 part potassium chlorate).

The Dowse Fuze—Medium Tension.—Fulminate of copper is said to have been discovered by Dr. John Davy. On August 27, 1867, Jabez B. Dowse, of Lockport, Ill., patented its application as a priming for electrical fuzes under the name of "copper amalgam." His formula is:

Finely divided copper, 3 parts; fulminate of mercury, 1 part.

Add about 30 per cent. of water; raise temperature to about 212° Fahr.; intimately mix. When about half the water has evaporated, charge as follows: Place 0.4 of a grain of the compound between small polished leaden discs and submit to a pressure of about 600 pounds; bottle for two days to prevent too rapid evaporation; attach wires, and place the primed discs in the exploding charge of the fuze.

Dowse prepared his copper by intimately mixing lamp-black with protoxide of copper in such proportions as to form carbonic acid gas with the oxygen, and heating to redness in a vessel from which the air was excluded. He states: "The manufacture of copper amalgam requires the utmost caution. I advise no person to attempt it unless he has been accustomed to handle fulminates." This caution is not unnecessary; and it might be well to add that with this priming the free ends of the fuze wires should always be kept twisted into good metallic contact until ready for use—

to guard against accidental explosions due to insensible disturbances of electrical equilibrium.

Dowse's fuze in appearance resembles a small tin pail, ½ inch in diameter and 2 inches high, charged with gunpowder, and containing two of his primed discs.

This fuze, considerably modified by different manufacturers, superseded the Beardslee fuze, and at one time chiefly supplied the markets in this country. The lead discs were omitted, and the priming in a state of powder was placed between the inner terminals of an ordinary fuze, which was charged with gunpowder or fulminating mercury, according to the explosive for which it was designed. By adding plumbago the extreme sensitiveness of the priming can be reduced, but no modification known to me renders it suitable for general use.

Samples of fulminate of copper fuzes were obtained from the inventor, and from H. J. Smith, C. A. Browne, and G. A Goodyear—all of whom were engaged in the business of supplying the market. They used different modes of preparing the copper and mixing the ingredients, and also added plumbago in different proportions.

The sample supplied by Dowse (in 1874) was essentially that described in his patent, but he stated that the method of manufacturing the priming had been some-
fuze contained two of the igniting discs to guard against a possible defect in one of them.

Smith obtained his copper by deposition from a strong aqueous solution of the sulphate by means of metallic iron. After washing, the metallic powder was treated with 1 ounce of muriatic acid in a quart of water; was again washed; was dried by steam heat; and finally was preserved under alcohol. He usually added plumbago, and, at my suggestion, increased the quantity to 35 per cent. Made upon this formula, most of the fuzes approach the limit of safety, and many hundreds were carefully used in practice at Willets Point without an accident. As soon, however, as a better priming was discovered they were discarded.

Browne deposited his copper in a similar manner, being careful at first to select bits of soft cast iron which would not coat. After the deposition had begun there seemed to be less difference in different pieces of iron in this respect. He preferred the granulated copper thus obtained to the impalpable powder deposited by zinc. The copper was strained and placed in a mixture of 1 part of muriatic acid to 9 parts of water; the black scum was removed, and the process was repeated, with a weaker mixture of the acid, until no scum rose. The copper was then strained and washed in pure water until the latter would not redden litmus paper. Finally, the metallic powder was removed by a sieve and preserved under alcohol.

His usual formula was 47 parts of copper, 47 parts of fulminate of mercury, and 6 parts of plumbago, prepared in water at 212° Fahr. Becoming satisfied that this composition was over-sensitive, he submitted, in February, 1872, samples for trial, as follows:

No. 1. Equal parts of fulminate of mercury and copper; water at 100° Fahr.
No. 2. 1 part of fulminate of mercury, 2 parts of copper; water at 100° Fahr.
No. 3. Usual formula, as described in the text above.
No. 5. 1 part of fulminate of mercury, 2 parts of copper; water at 212° Fahr.
6. "Fuzes in market." Probably same priming as No. 3.

One sample purporting to be of his manufacture had previously been received from General Newton in June, 1871. It was decidedly less sensitive than those supplied for these special tests, as will be seen below.

Goodyear's sample was received in April, 1874, after all varieties of this priming had ceased to be practically used at Willets Point. His exact process of manufacture was not stated, but it probably did not differ essentially from that adopted by Smith.

The following table exhibits the results of electrometer tests of these several fuzes made after the instrument had been perfected. Many earlier measurements are omitted because they cannot now be certainly reduced to the adopted standard.

The Dowse fuze.

ELECTROMETER TESTS.

Maker.	Date.		Number tested.	Igniting charge in microfarads.			Remarks.
	Made.	Tested.		Least.	Greatest.	Mean.	
Dowse....	January, 1874 ...	February, 1874 ..	8	0.06	0.66	0.32	
	....do	March, 1879	14	0.03	0.46	0.15	
	....do	....do	10	0.03	0.23	0.09	Mean resistance, 298,000 ohms.
	....do	....do	10	0.03	0.87	0.33	Mean resistance, 282,110 ohms.
Smith.....	August, 1870	March, 1879	11	0.07	0.23	0.14	Original trade article.
	June, 1870.......	June, 1871.......	19	0.03	0.42	0.22	20 per cent. plumbago.
	July, 1871	1872 and 1875....	7	0.06	0.85	0.39	Do.
	June, 1871.......	July, 1871	16	0.03	1.21	0.87	35 per cent. plumbago.
Browne...	February, 1872 ..	1872 and 1879....	6	0.05	0.07	0.06	Sample No. 1.
	....do	February, 1872 ..	5	0.06	0.06	0.06	Sample No. 2.
	....do	1872 and 1879....	13	0.03	0.06	0.04	Sample No. 3.
	....do	February, 1872 ..	7	0.06	0.06	0.06	Sample No. 5.
	....do	....do	9	0.06	0.06	0.06	Marked "In use."
	....do	April, 1879	19	0.03	0.09	0.05	Mean resistance, 650,600 ohms.
	Not known	July, 1871	23	0.26	1.28	0.69	From General Newton, July, 1871.
Goodyear.	April, 1874	April, 1874	11	0.06	0.50	0.19	
	....do	April, 1879	10	0.03	0.06	0.04	Mean resistance, 5,015,000 ohms.

None of the fuzes in the foregoing tests failed to explode, except one which was defective in insulation; and the same remark may be made of the many hundred fired in various practical trials. Hence, this priming may be regarded as certain to explode, lapse of time (eight years) causing no deterioration.

The addition of plumbago is a decided improvement, by reason of its effect in reducing the over-sensitive character of the priming; but it is not a certain corrective,

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as may be seen by examining the column showing the *least igniting charge.* Probably from the imperfection of mechanical mixing, some individual fuzes remain very dangerous, and I know of no test by which they can be detected.

The resistance of fulminate of copper fuzes varies within wide limits (10 megohms to 88 ohms in the samples measured), depending, of course, upon the percentage of the metallic copper and plumbago, and upon the length of the break between the wire terminals. The average may be taken at about 300,000 ohms; but little importance should be attached to this matter with frictional electricity, since there seems to be no law connecting the resistance and sensitiveness of the individual fuzes.

The Browne Fuze (No. IV)—High Tension.—This excellent fuze was submitted to me for testing with those named above on February 9, 1872. It proved to be safe, certain, uniform, and, as experience has shown, not liable to deteriorate from lapse of time or exposure to ordinary dampness. It was immediately placed in the market by the Laflin & Rand Powder Company, and soon superseded the fulminate of copper fuze on the Hoosac Tunnel and in the trade generally.

Like the rest of its class this priming is specially suited for frictional apparatus. It cannot be fired by an ordinary voltaic battery, or by most kinds of magneto-electric apparatus. The original composition was the following:

	Parts.
Fulminate of mercury	53
Sulphuret of antimony	13
Powdered antimony	34

As supplied to the trade the usual formula has been four, one, and three parts, respectively, this slight modification being made solely for convenience of manufacture. The two compositions do not differ electrically.

The mixing of the ingredients is done in a dry state. The metallic antimony is pulverized in a mortar and passed through a fine sieve. The sulphuret of antimony (black preferred) and the fulminate of mercury are also carefully sifted. To mix the composition the fulminate is again passed through a sieve upon a sheet of paper, and upon it are sifted, first the metal and then the sulphuret. The paper is then bent a few times, and the whole compound is passed twice through a coarser sieve, which completes the process. Only a small quantity should be treated at once, and always behind a thick glass plate, secured vertically upon the table as a protection to the operator.

The following table exhibits the results of the various electrometer tests of this priming:

The Brown fuze (No. IV).

ELECTROMETER TESTS.

Maker.	Date.		Number tested.	Igniting charge in microfarads.			Remarks.
	Made.	Tested.		Least.	Greatest.	Mean.	
Browne...	February, 1872..	February, 1872..	20	1.83	2.81	2.36	
	....do	May, 1872	9	2.47	3.40	3.07	
	....do	February, 1873..	6	1.54	2.91	2.22	
	....do	March, 1874	5	1.04	1.97	1.51	
	July, 1872	September, 1872.	26	2.35	7.85	2.63	Four required Smith machine.
	....do	October, 1872	5	2.28	3.12	2.68	
	....do	February, 1873..	5	1.83	2.81	2.31	
	....do	August, 1874	8	1.04	1.97	1.47	
	....do	March, 1879	4	1.80	2.67	2.25	
	August, 1872	1872 and 1873	20	1.54	3.21	2.41	
	March, 1873	March, 1873	9	1.67	2.59	2.02	
	....do	April, 1873	11	1.54	2.70	1.99	
	....do	April, 1874	70	1.28	3.08	2.07	
	....do	July, 1874	3	1.97	2.11	2.02	
	....do	March, 1875	7	0.85	2.00	1.34	
	....do	January, 1876	10	1.80	2.59	2.18	
	....do	March, 1879	31	1.04	3.31	2.12	
	April, 1873	May, 1873	12	1.54	3.02	2.35	
	....do	April, 1873	10	1.21	1.69	1.42	
	May, 1873	May, 1873	10	1.38	2.35	1.86	
	....do	....do	3	3.02	3.31	3.18	
	....do	....do	17	1.69	2.89	2.12	
	June, 1873	June, 1873	2	1.83	2.47	2.15	
	December, 1873..	December, 1873..	24	1.54	2.91	2.15	
	....do	February, 1874..	25	1.32	3.02	2.05	

From these tests it appears that out of 352 of these fuzes, made at ten different dates from materials purposely varied, none failed to explode, and that only 5 required a charge exceeding 3.5 microfarads. These five were from the same lot, and probably had some exceptional defect.

Also, that out of these 352 fuzes not one exploded with a charge below the standard of safety; and it may be added that a stream of uncondensed sparks fully a quarter of an inch long, from a small frictional machine, has often been passed through these fuzes for several minutes, continuously, without a single instance of explosion.

Also, that the average charge required for ignition (see page 198) was about two microfarads, a charge much within the capacity of the frictional apparatus usually employed in blasting, even when twenty holes are to be fired simultaneously.

Also, that after remaining in store for six years at Willets Point no sign of deterioration could be detected.

For these reasons this priming has been approved and adopted for cases in which a high-tension fuze may be required in our military mining service. It has often been used in experimenting with sub-aqueous explosions at Willets Point, and without a single failure. If intended to be placed in *nitro-glycerine*, electrical fuze plugs must always be carefully constructed to prevent the oil from reaching this (or any other) priming, since leakage is destructive to sensitiveness. Our adopted pattern is quite safe from this difficulty, which on the Hoosac Tunnel, at one time, gave rise to much trouble and caused many miss-fires

The new priming was not adopted without a systematic study of the effect of varying the proportions of the several ingredients. The following experimental compositions were made and tested with this object in view, the mixing in all cases being dry:

Priming I, fulminate of mercury, 100 parts; sulphuret of antimony, none; powdered antimony, none.
Priming J, fulminate of mercury, 50 parts; sulphuret of antimony, 50 parts; powdered antimony, none.
Priming K, fulminate of mercury, 80 parts; sulphuret of antimony, none; powdered antimony, 20 parts.
Priming L, fulminate of mercury, 67 parts; sulphuret of antimony, none; powdered antimony, 33 parts.
Priming M, fulminate of mercury, 57 parts; sulphuret of antimony, none; powdered antimony, 43 parts.
Priming N, fulminate of mercury, 50 parts; sulphuret of antimony, none; powdered antimony, 50 parts.
Priming O, fulminate of mercury, 44 parts; sulphuret of antimony, 11 parts; powdered antimony, 45 parts.
Priming P, fulminate of mercury, 40 parts; sulphuret of antimony, 10 parts; powdered antimony, 50 parts.

Modifications of Browne's priming.

ELECTROMETER TESTS.

Experimental priming.	Date.		Number tested.	Igniting charge in microfarads.			Remarks.
	Made.	Tested.		Least.	Greatest.	Mean.	
Priming I	May, 1873	May, 1873.......	5	12.75	12.75	12.75	Three required 4 turns Smith machine.
Priming J	....do	....do	10	3.92	5.33	4.48	
Priming K....	....do	....do	10	1.83	5.33	3.05	
Priming L	....do	....do	13	3.02	6.45	4.43	
Priming M....	....do	....do	10	3.44	6.20	4.84	
Priming N....	....do	....do	21	2.19	12.75	3.43	Next greatest 3.92 microfarads.
Priming O	1872 and 1873....	1872 and 1873....	23	1.54	3.63	2.67	
Priming P	August, 1872....	September, 1872.	4	2.47	4.08	3.37	

These tests were all made with the Leyden jar as a condenser (see page 192), and the number of fuzes tested was evidently not great enough to render it certain that precise averages were obtained; but they were regarded as sufficient to show that Browne's original proportions were well chosen, and they were accordingly adopted.

The Mowbray Fuzes—High Tension.—George M. Mowbray supplied nitro-glycerine, of excellent quality, in large quantities to the Hoosac Tunnel and to other similar works. Accidents in its use, even when really due to the over-sensitive character of the electrical fuzes, were often wrongly attributed to the dangerous nature of that new explosive. Accordingly, he was keenly alive to the importance of improving the supply in the market; and both by his writings and by his efforts to discover a safe priming, he contributed to bring about this desirable result.

His first efforts were directed to imitating or improving the Abel priming; but, as already seen, he failed in so doing.

His next step was to devise an entirely original priming, which he patented on March 5, 1872. Its composition was the following, the mixture being effected when the components were still moist after being ground with alcohol; subsequently, it was dried and passed through a fine sieve:

Potassium chlorate, 1 part; mercuric sulphide, 3 parts.

This patent was usually known as his "vermilion" fuze; but it proved to be deficient in sensitiveness, as will be seen below. The dangers resulting from frequent miss-fires with it, were no less formidable than those arising from the other and more common defect of over-sensitiveness.

On April 7, 1873, he sent me three new samples for trial, of which the composition was the following:

Sample A.—Fulminate of mercury, 5 parts; powdered antimony, 8 parts.
Sample B.—Fulminate of mercury, 8 parts; powdered bismuth, 5 parts.
Sample C.—Fulminate of mercury, 5 parts; powdered cadmium, 4 parts.

The metallic ingredients were ground very fine, and mixed under water with the fulminate. Sufficient fluid was used to cover the solid materials about half an inch. The vessel was allowed to stand for twenty-four hours, the contents being occasionally stirred; when the excess of water was decanted and the mixture was dried. Sample C was charged moist, the others dry.

The following table exhibits the results of the electrometer tests of these several primings:

The Mowbray fuzes.

ELECTROMETER TESTS.

Priming.	Date.		Number tested.	Igniting charge in microfarads.			Remarks.
	Made.	Tested.		Least.	Greatest.	Mean.	
Vermilion	April, 1873	April, 1873	3	3.44	3.44	3.44	One failed with Smith machine.
Do.	do	April, 1879	20	4.37	10.01	6.22	Six failed with 13 microfarads.
Sample A	do	May, 1873	13	1.83	2.81	2.25	
Do.	May, 1873	March, 1874	13	0.93	3.02	1.75	
Do.	do	May, 1879	22	1.04	3.92	2.60	
Sample B	April, 1873	April, 1873	6	0.66	2.59	1.40	
Sample C	do	do	5	1.38	2.35	1.97	

These tests show that while the vermilion fuze lacks the requisite delicacy, the other three are all worthy of study. Sample A was selected as probably the best, and a supply was ordered; which, as shown in the table, has been occasionally subjected to tests with the electrometer, and has often been used in practical torpedo experiments. No failure to explode has occurred, and it is believed to be a safe, uniform, and certain priming, not liable to deterioration from lapse of time or exposure

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in a damp climate. Indeed, it appears to be electrically the equivalent of its predecessor, the Browne No. IV fuze, which it resembles in chemical composition.

Like all of its class (high tension) it is only suited for use with electricity of high potential. Mowbray has adopted it for his Powder Keg frictional battery, and it bears a good reputation in this country.

The Giant Powder Company Fuze—High Tension.—This well-known company supply a fuze for use with their dynamites, which has been carefully studied. The composition and mode of manufacture are not made public, but a rough analysis furnished the following results:

	Parts.
Oxide of zinc	70.36
Oxide of lead (litharge)	10.03
Ammonia nitrate of silver (calculated from silver present)	22.52
	102.91

The fuze exhibits an exceptionally high resistance, which, combined with its sensitive character, renders some care necessary in deciding upon its exact classification as to safety. The samples were received in March, 1874, and the following table exhibits the results of the electrometer tests.

The Giant Powder Company fuze.

ELECTROMETER TESTS.

Maker.	Date.		Number tested.	Igniting charge in microfarads.			Remarks.
	Made.	Tested.		Least.	Greatest.	Mean.	
Detwiller, Street & Co.	March, 1874	March, 1574	10	1.38	2.11	1.84	Condenser, jar,
	....do	....do	4	0.75	1.02	0.89	Condenser, mica.
	....do	March, 1879	10	0.38	0.61	0.52	Condenser, No. 1.
	....do	....do	10	0.94	1.29	1.09	Condenser, No. 2.
	....do	....do	10	0.35	0.45	0.38	Condenser, none.
	....do	April, 1879	10	0.45	2.11	1.33	Condenser, jar.

This fuze has already been discussed when treating of the theory of ignition of high-tension fuzes (page 197); and the conclusion that it explodes with a charge of about 0.4 of a microfarad when the potential is high enough to force this quantity through the priming, is there reached. It must, accordingly, be classed as over-sensitive, although perhaps not very dangerously so. The priming appears to be certain in its action, and to be free from any tendency to deterioration from long storage.

The Smith Gold Foil Fuze.—This fuze, which was submitted to me for trial by the Laflin & Rand Powder Company, in May, 1876, is decidedly original. The object proposed by the inventor, H. J. Smith, was to combine a very low resistance with a safe priming; and thus to permit large numbers of fuzes to be fired simultaneously with a frictional machine, without danger either of premature explosions or of missfires. The enormous resistance of the ordinary safe primings used with this class of apparatus, restricts the number of ignitions, in practice, to from 15 to 20 holes—the connection, of course, being in series, since a spark will not subdivide according to any uniform rule. This limit Smith hoped to extend.

The fuze was patented in February, 1876, and is to be regarded as including much more than a mere modification of priming. It embodies a new idea in fuze manufacture which may hereafter be susceptible of development, and which at any rate opens the whole problem of primings anew to investigation. At an earlier period, a thorough experimental study would have been given to this invention; but the general introduction of low-tension (fine wire) fuzes into our market, and their exclusive adoption for the Torpedo Service have heretofore prevented me from undertaking it. The new fuze in the shape devised by Smith was carefully tested, as will be seen below.

This fuze differed from those in the market in some unimportant details of construction—the copper conducting wires being replaced by iron insulated with cotton, etc.; but the real characteristic feature consisted in a strip of gold foil (four times the thickness usually employed in gilding) cemented to the head of the wooden plug between the inner terminals of the fuze wires, which were bent or crimped down firmly upon it. This arrangement afforded a continuous metallic circuit for the spark, but did not prevent the ignition of the priming (the gold foil being usually deflagrated by its passage). The priming consisted of equal parts of potassium chlorate, sulphuret of antimony, and fulminate of mercury. No special priming chamber was provided, the priming and exploding charge being the same composition.

The electrical resistance of the first sample of these fuzes lay between 0.4 ohms and 3 ohms; but later samples varied between much wider limits. Some gave from 4 to 40 ohms, indicating a bad contact; and others gave a megohm, indicating none whatever. Corresponding differences in the tests showed that the first sample was decidedly the better—the result doubtless of more care in the manufacture. The following table exhibits the results of these tests, no failures to explode occurring.

The Smith gold foil fuze.

ELECTROMETER TESTS.

Maker.	Date.		Number tested.	Igniting charge in microfarads.			Remarks.
	Made.	Tested.		Least.	Greatest.	Mean.	
Laflin & Rand Powder Co.	May, 1876	May, 1876	13	1.29	1.88	1.54	
	....do	April, 1877	10	1.41	2.82	1.85	
	....do	October, 1877	10	1.35	2.36	1.91	
	September, 1877	....do	21	1.16	3.55	2.46	Ten showed no contact.
	December, 1877	January, 1878	10	1.41	3.44	2.32	

These tests certainly indicate that this fuze is safe, uniform, and, if carefully made, of a very good degree of sensitiveness. The tests for permanency were not continued long enough to be decisive, but a slight tendency to lose sensitiveness is possibly indicated. This, if true, is of no serious importance, since it can certainly be corrected by changing the priming. The fuze has been in the market for several years and bears a good reputation.

Although specially intended for frictional apparatus, this fuze can usually be fired by a voltaic battery; and, indeed, by the whole class of magneto-electric apparatus designed for use with low-tension (fine wire) fuzes. A few tests were made, by the method soon to be explained, to determine its merits for this use; and although they did not result favorably they will be given in full, because certain interesting facts were developed.

The Smith gold coil fuze.

VOLTAIC BATTERY TESTS.

Sample.	Resistance.			Firing current.	Remarks.
	Cold.	At ignition.	Difference.		
	Ohms.	*Ohms.*	*Ohms.*	*Webers.*	
1	0.83	0.92	+0.09	1.06	
2	1.00	0.96	−0.04	1.07	
3	3.00	....	......	....	Circuit ceased at 0.25 webers.
4	2.28	2.39	+0.11	0.35	
5	1.68	....	......	....	Circuit ceased at 0.25 webers.
6	1.32	1.50	+0.18	0.62	
7	1.60	1.74	+0.14	0.42	
8	1.00	1.44	+0.44	0.62	
9	2.45	2.64	+0.19	0.38	
10	6.69	2.13	−4.56	0.61	
11	0.96	1.08	+0.12	0.86	
12	1.33	1.30	−0.03	0.48	
Mean current				0.64	

From this table it appears that of the twelve fuzes, two failed by the burning off of the gold foil circuit under test. Possibly if a strong current had been instantly applied, this would not have occurred; but, joined to the considerable variation in the firing current, the fact is sufficient to condemn the arrangement for use as a low-tension fuze. In seven fuzes the resistance increased, normally, by the gradual heating of the gold foil bridge; but in the other three this resistance diminished—in one sample very much (4.56 ohms). It will hereafter appear that unless the bridge be soldered to the wire terminals this result is always liable to occur with low-tension fuzes, probably from the expansion of the bridge and the consequent motion of the points of contact as the temperature rises.

The Goodyear Fuze—High Tension.—In January, 1875, George A. Goodyear submitted, for trial, a new high-tension priming, of which the composition was the following:

	Parts.
Picrate of lead	60
Potassium chlorate	25
Potassium nitrate	15

The resistance of his fuzes charged with this priming exceeded 10 megohms, and they were only suited for use with electricity of high potential, such as that supplied by frictional machines, Siemens' spark machine, and induction coil apparatus.

Six fuzes were immediately tested with the electrometer, giving for the least igniting charge, 0.29 microfarads; greatest, 0 85 microfarads; and mean, 0.47 microfarads. Repeated in April, 1879, the test gave for four fuzes: least, 0.14 microfarads; greatest, 1.14 microfarads; mean, 0.56 microfarads. According to the adopted standard of safety this priming must, therefore, be classed as over-sensitive. It seems to be fairly uniform and not liable to deterioration after a storage of four years; but more numerous trials, of course, are requisite before any decided opinion can be formed on these points. It has never been placed in the market.

The Hill Fuze—Medium Tension.—This fuze, devised by Prof. W. N. Hill, of the torpedo station at Newport, is adopted in the United States Naval Torpedo Service for use with frictional electricity, and, in a slightly modified form, for contact primers.

The formula for the electrical priming is the following:

	Parts.
Potassium chlorate	45.00
Sulphide of antimony	20.75
Red phosphorus	5.75
Plumbago	28.50

For contact torpedoes it is modified as follows:

	Parts.
Potassium chlorate	60.5
Sulphide of antimony	33.5
Red phosphorus	6.0

The ingredients (dry) are first prepared separately, being pulverized in an agate mortar, and care being taken that the amorphous phosphorus is free from ordinary phosphorus. Alcohol is poured in the mortar; the potassium chlorate is added, and ground thoroughly with a pestle; the sulphide of antimony is then added, and the grinding is repeated; the phosphorus follows, and is well incorporated in the same manner; lastly, the plumbago is inserted, and the whole is well ground together. The excess of alcohol is then removed, and the proper charges are taken out with a wooden spatula and placed on bibulous paper to thoroughly dry. When wet with alcohol this priming is quite safe, but when dry it is very sensitive and should be handled behind glass. The fuzes may be primed with it in either state, as preferred.

Fuzes with this priming have never been placed in the market, but they have given results satisfactory to the naval authorities. A few tests with my electrometer indicate that it is a very safe fuze, requiring several microfarads for ignition.

Experimental Primings.—It only remains to notice a few of the best primings made

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for trial during the progress of investigations in this subject at Willets Point, and not already mentioned in the foregoing pages as modifications of other fuzes. Such are:

Priming Q.—Potassium chlorate, 44 parts; fulminate of mercury, 45 parts; horn carbon, 1 part.

Priming R.—Potassium chlorate, 36 parts; sulphuret of antimony, 36 parts; sulphuret of copper, 28 parts.

Priming S.—Potassium chlorate, 42 parts; potassium ferro-cyanide, 25 parts; powdered sugar, 21 parts; horn carbon, 12 parts.

Priming T.—Potassium chlorate, 34 parts; sulphuret of antimony, 33 parts; potassium bichromate, 10 parts; ferric peroxide, 13 parts; horn carbon, 10 parts.

Priming U.—Potassium chlorate, 45 parts; bisulphuret of tin, 44 parts; horn carbon, 11 parts.

Of these samples Q varied in resistance between 5,000 ohms and 1 megohm, R between 4,000 and 11,000 ohms, and the rest all exceeded 1 megohm.

Special primings.

ELECTROMETER TESTS.

Primings.	Date.		Number tested.	Igniting charge in microfarads.			Remarks.
	Made.	Tested.		Least.	Greatest.	Mean.	
Q	January, 1876.	January, 1876.	10	1.80	3.33	2.61	
R	do	do	20	0.53	1.10	0.78	
S	do	do	12	2.19	5.61	3.25	Two failed at 5.61 microfarads.
T	do	do	11	2.82	5.02	3.60	One failed with Smith machine.
U	do	do	11	2.00	2.55	2.26	

Perhaps these primings all merit more study, especially sample R, which seems to come nearest the minimum safety standard of the many fuzes tested; but the pressure of other work, and the final adoption of the low-tension class for our submarine mines, have prevented me from continuing the investigation.

The Browne Compound Fuze—High and Low Tension.—This ingenious device of C. A. Browne was received in June, 1872. It is designed for use either with a voltaic battery or with frictional electricity. It consists of a wooden spool, one end of which is closed by a small hollow plug containing a platinum wire fuze of the ordinary form; the other is closed in like manner by a similar plug arranged as a high-tension fuze. Between the two, inside the spool, is placed the ordinary detonating charge of fulminating mercury. The main fuze wires are connected with each of these small fuzes, with the high tension directly, and with the low tension through two 5-foot lengths of No. 22 copper wire, B. W. G., insulated with a double wrapping of cotton, and coiled round the outside of the spool.

When the requisite voltaic current (about 0.85 webers) is sent through this arrangement, it follows the long route and explosion results from the heating of the fine wire.

When a spark is employed, from its well-known tendency to seek the shortest route even at the cost of overcoming a great resistance, it ignites the high-tension priming (Browne No. IV) without sensible subdivision through the shunt.

For ordinary uses this fuze possesses no merit commensurate with its increased cost; but it is easy to see how, by a slight modification, it might be arranged for a torpedo which is designed to be fired either by judgment or by the action of a vessel upon a circuit closer.

Special Experiments.—Of many trials made from time to time with fuzes of the classes now under consideration, a few are deemed worthy of mention here.

The familiar fact that any disturbance of electrical equilibrium in one conductor will induce a disturbance in that of a neighboring conductor insulated from it, suggested to C. A. Browne a safe method of employing fuzes which, if joined in the main circuit, are dangerously over-sensitive; and he communicated the idea to me in March, 1872. It consisted in throwing a short portion of one of the main leading wires into a spiral and wrapping the wires of one of his fulminate of copper fuzes (each wire 3 feet long) around it continuously in opposite directions, and then joining the ends; thus bringing the fuze in the middle of a short secondary circuit entirely separate from the leading wires. We found that a spark from a Smith machine, about a quarter of an inch long, passed through the latter would fire the fuze by induction, while ordinary voltaic and magneto-electric currents produced no effect.

I made several experiments to develop this idea, and found it to be quite practicable to increase the sensitiveness to any desired extent. By using 30 inches of well insulated wire, No. 20 B. W. G., as the primary coil in the main circuit, and enveloping it with from 8 to 16 feet of No. 26 B. W. G. for the secondary (or fuze) circuit, the Abel and other safe fuzes could be easily fired; while with much shorter wires fuzes ordinarily dangerous could be safely used and certainly exploded. The probability of increasing by this method the number of simultaneous ignitions suggested itself, since the spark is not required to traverse the immense resistance opposed by the fuzes, but the investigation was not pursued.

The reverse problem—how to prevent induced currents from causing premature explosions—was far more important, so long as high and medium tension fuzes formed part of our submarine mining system; and it therefore exacted careful study. So far as the investigation was confined to my automatic operating apparatus, the results no longer have any practical importance, and hence will not be reported here; but where they possess general interest they will be put on record.

The experiments of which the following is a brief summary, were begun in 1872, to verify and investigate certain results reported in Europe.

Two wires insulated with India-rubber protected by tape wrapping (resistance about 18 ohms per statute mile) were laid side by side from the old laboratory to the

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end of the engineer wharf at Willets Point, a distance of about 1,000 feet. At the wharf, a fuze was attached to each wire, and the circuits were continued to sheet-brass earth plates, 12 by 12 inches, placed in the water 50 feet apart. At the laboratory, one of the wires was attached to a Smith machine, of which the other pole was put to earth; and the other wire was insulated in the air 50 feet from the instrument. Whether Abel or Browne No. IV fuzes were used, both exploded when a 2-inch spark was sent through the circuit connected with the machine. A like result was usually obtained with the two leading wires, 3, 4, and 5 feet apart; but when they were over 6 feet apart, a Browne No. IV fuze in the detached circuit always failed to explode.

With wires arranged as above, side by side, my extra current coil (see next chapter) operated by 50 large Smee cells, caused the explosion of a Browne No. IV fuze in the detached circuit only once in seven trials.

A coil of small wire, having a resistance of 12.5 ohms, was next placed in the detached circuit close to the fuze and on the land side. This seemed to protect the fuze (Browne No. IV) against explosion, whether the extra current coil or a Smith machine giving a 2-inch spark was used.

The taped wires were now replaced by single conductor armored cables of the pattern adopted for our Torpedo Service. A 2-inch spark from a Smith machine usually, but not always, fired the fuze in the detached circuit, whether the cables laid side by side, or were 1, 2, 3, or 4 feet apart.

Under like conditions, a 1-inch spark exploded both fuzes with the cables 1 foot apart; but a half-inch spark failed to ignite the detached fuze.

The circuit including the Smith machine, was now detached from the earth plates, the return being by the iron armor of the torpedo cable. Results similar to those recorded above were obtained.

The Smith machine was now replaced by a small induction coil, giving an uncondensed spark 5 inches in length. Results similar to those recorded above were obtained; but with more failures, due probably to the difficulty of securing good insulation for a spark of so high potential.

The partial success attending the attempt to arrest the induced spark by the introduction of the small resistance coil (12.5 ohms) between the fuze and the cable, suggested the introduction of a small break in the circuit (about 0.01 of an inch) at the same place—a similar break being also similarly placed in the other cable. This proved perfectly successful with 1-inch sparks from a Smith machine, with 5-inch sparks from the induction coil, and with ¼-inch condensed sparks from the portable induction coil devised for judgment firing (see next chapter)—Browne No. IV fuzes being used.

The effect of submerging the two armored cables in salt water was next tested. With two cables 700 feet long, thus submerged, joined to land leading wires 400 feet long, the two circuits being about 1 foot apart, a Browne No. IV fuze in the detached circuit could not be fired by a 2-inch spark; but over-sensitive (fulminate of copper) fuzes could be thus exploded. No breaks were used in these trials.

In 1874 these experiments were continued with 7-strand multiple cables, of the pattern adopted for our submarine mining service (India-rubber insulation).

A length of 1 mile coiled upon a drum was first used, on land.

With a Siemens spark machine connected to one core at one end, the other cores being insulated, and seven Browne No. IV fuzes uniting the single metallic return circuit to the seven cores at the other end, all exploded; but breaks of 0.01 of an inch, inserted as above, quite destroyed the inductive effect. An inch spark from a Smith machine, however, fired several fuzes even when the breaks were used.

When the earth was used for the return circuit, the Siemens spark machine occasionally fired wrong fuzes by induction, notwithstanding the protection of $\frac{3}{16}$-inch breaks. In fine, I reached the conclusion that the induction in a mile of multiple cable coiled on its drum on land, is too great to be controlled, whether a Smith machine, or a Siemens spark machine, or even the service portable induction coil, giving $\frac{1}{4}$-inch condensed sparks, be used.

The same cable was then submerged, with land leading wires 1,000 feet long placed side by side, and the experiments were repeated, the fuzes (Browne No. IV) being at Fort Schuyler and the igniting apparatus at Willets Point, and the earth making the return circuit. As had been anticipated from the results obtained by submerging the single conductor cables, no trouble occurred from induction, whether a Smith machine giving a 2-inch spark, or a Siemens spark machine, or a service induction coil ($\frac{1}{4}$-inch condensed spark) was used—the breaks of 0.01 of an inch proving a sure protection against accidental explosions. All these apparatus fired the fuze through the break on the selected core without difficulty. Hence, I should apprehend no serious annoyance in operating mines with fuzes thus protected, *when the cables are submerged and well insulated.* It must, however, be admitted that danger from induced currents is a very serious objection to the employment of either medium or high-tension fuzes in submarine mining; and it had much to do with their ultimate exclusion from our system.

LOW-TENSION FUZES.

The name low tension is applied to that class of electrical fuzes which are exploded by the heating of a very fine wire bridge, uniting the insulated conductors in the priming chamber, to a degree sufficient to ignite the priming in which it is embedded. Such fuzes differ in the kind, diameter, and length of the wire, and in the chemical composition of the priming.

Low-tension fuzes admit of two distinct kinds of tests—one, for service, to verify the condition of an individual fuze; the other, elaborate, to determine the general

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character of a particular pattern both in respect to sensitiveness and to uniformity. The latter is destructive to the fuze, the former is not.

The former test consists in measuring the electrical resistance of the fine wire bridge and insulated conductors by any of the usual methods, and comparing the result with the known standard value. If the two accord, the circuit is in good order; and hence it may be assumed that explosion will follow if the requisite current be employed.

The latter test is more elaborate. It should include the accurate measurement of the minimum strength of current required to heat the fine wire bridge sufficiently to ignite the priming; the electrical resistance of this wire when cold; and the same, at the instant of explosion. After trying various plans for accomplishing these objects, I finally devised the following, which has proved to be perfectly satisfactory.

Method of Elaborate Testing.—The instruments employed consist of a Helmholtz-Gaugain galvanometer, of which the weber coefficient is accurately known; a Kirchhoff-Wheatstone bridge; a standard ohm; a Siemens universal galvanometer for use with the bridge; a Wheatstone rheostat for gradually and uniformly reducing the resistance in circuit; a set of coarse wire resistance coils aggregating about 100 ohms; and a battery of from three to six small Grove cells.

The connections are shown on Plate XXII, Fig. 1. Three observers are necessary. One stations himself at the bridge, to manipulate the contact piece "a" so as to keep the needle of the delicate Siemens galvanometer at zero; another watches the indications of the Helmholtz-Gaugain galvanometer and notes the reading at the instant of explosion; the third regulates the resistance of the circuit by the coils and by adjusting the Wheatstone rheostat.

The first object is to ascertain the fixed resistance of the side of the bridge in which the fuze is to be placed. This is done by unplugging a large resistance in the set of resistance coils; connecting together the wires to which the fuze will be attached; and then measuring the resistance of the circuit—which comprises the Helmholtz-Gaugain galvanometer (coarse coils) and the leading wires. The result, deducted from all subsequent measurements, will leave the true fuze resistances sought.

The fuze is now attached, and its resistance when cold is measured in the usual way. It is important that enough resistance shall be unplugged in the coils to avoid any heating of the platinum during this test. For the same reason, the contacts at "a" should be short.

All being now in readiness for the final test, the resistance coils are plugged out of circuit; and enough wire being upon the wooden cylinder of the Wheatstone rheostat to prevent the explosion of the fuze, the contact piece "a" is closed. The latter is then gradually moved along the wire so as to preserve the balance of the bridge.

Meantime, the wire is uniformly wound from the wooden to the brass cylinder of the Wheatstone rheostat, thus reducing the resistance in the fuze circuit; and the needle of the Helmholtz-Gaugain galvanometer increases its deflection accordingly. This motion must be kept steady by regulating, if necessary, the rate of transfer of the wire. Finally, the fuze explodes: the corresponding resistance, which has been gradually increasing as the temperature of the platinum wire rises, is shown by the reading of the bridge; and the current in webers causing the explosion may be computed from the reading of the Helmholtz-Gaugain galvanometer.

Repeating this operation with the entire sample, the character for uniformity and sensitiveness, and hence the care used in manufacture become known. During the last half of the tests the direction of the current should be reversed, to correct any index error in the Helmholtz-Gaugain galvanometer.

The precision of the resistances measured by this plan depend (1) on the correctness of the standard ohm, and (2) on the uniformity and symmetrical form of the wire of the Kirchhoff-Wheatstone bridge. The accuracy of the current measurements depends on the care used to determine the weber coefficient of the Helmholtz-Gaugain galvanometer. The plan for the latter determination adopted at Willets Point has usually been the following. If close attention be given to every detail, much greater accuracy may be obtained than by the usual plan of computing the value from the dimensions of the coils and the horizontal intensity of the earth's magnetic force.

A constant battery sufficiently powerful to deflect the galvanometer at least 50° is provided. Its poles are connected by an exterior circuit containing the galvanometer, a box of resistance coils, and a mercury key for opening and closing. A second set of leading wires are attached to the poles of the battery, and so connected with a trigger-key, a condenser, and a Thomson reflecting galvanometer, that the effective electromotive force acting upon the exterior circuit can be determined at any desired instant by comparing the swing with that previously given by a standard Clark cell, by Law's method. All being in readiness, the exterior circuit is closed; and as soon as the Helmholtz-Gaugain galvanometer needle has settled at any suitable deflection (a) the corresponding effective electromotive force ($E_{\prime\prime}$) is measured by springing the trigger-key. The resistance of the exterior circuit ($R_{\prime\prime}$) being accurately known, the value of the weber coefficient (K) may be computed from the following equation, by substituting the known numerical values of the quantities in the second number:

$$K = \frac{E_{\prime\prime}}{R_{\prime\prime} \tan a}$$

Reversing the battery, to eliminate index error, the determination is repeated; and a mean of the two results is counted as one observation. By varying the amount unplugged in the resistance coils and repeating the work, sufficient data may be obtained to determine, by the method of least squares, the numerical value of the Weber coefficient within any desired degree of precision.

The Wire Bridge.—In order to choose the kind and dimensions of wire most suitable for forming the bridge, the general theory governing the heating effects of electrical currents should be considered.

According to Joule's law, if we represent by H the total quantity of heat developed in the time T in a circuit of which the resistance is R and the strength of current C:

$$H = C^2RT$$

But by Ohm's law we have for the strength of current (C) developed by an electric generator of which the internal resistance is $R_,$ through an external circuit of which the resistance is $R_{,,}$:

$$C = \frac{E}{R} = \frac{E}{R_, + R_{,,}}$$

Combining these two equations, and reducing:

$$H = \frac{E^2 T}{R_, + R_{,,}}$$

This equation is only applicable to the entire circuit; but since heat developed in the generator can accomplish no useful purpose, it is well to consider the internal and the external portions separately. Denoting the heat generated in these portions by $H_,$ and $H_{,,}$ respectively, we have, since by Joule's law they are proportional to the corresponding resistances:

$$H_, = \frac{E^2 T R_,}{(R_, + R_{,,})^2}$$

$$H_{,,} = \frac{E^2 T R_{,,}}{(R_, + R_{,,})^2}$$

The electrical resistance of a conductor is directly proportional to its length (l) and inversely proportional to its cross-section (πr^2). It is also directly proportional to the specific resistance of the material of which it is composed (ρ)—understanding by this term the quotient obtained by dividing the resistance of a unit of volume of this material by that of the unit of volume of some material adopted as the standard, both being at the standard temperature. Hence, if the exterior circuit be homogeneous and of uniform cross-section—

$$R_{,,} = \frac{\rho l}{\pi r^2}$$

If the exterior circuit consist of a homogeneous wire insulated by a homogeneous dielectric, and having a uniform cross-section (πr^2) throughout its entire length (l), the distribution of heat will be uniform; and (ϑ), the consequent rise in temperature in the time T, will vary inversely with the specific heat (S) of the kind of metal composing the conductor, and with the mass of the wire to be heated ($\pi r^2 l$). The loss of heat to surrounding bodies by radiation and conduction increases very rapidly as the temperature attained by the wire rises, and after a certain time will equal the whole heat developed by the current; but since the wire is supposed to be surrounded by a poor conductor of heat, the loss in the ***first instant*** after the circuit is closed will be so small that for the present purpose it may be neglected; and, under this limitation, the following equation may be accepted as approximately indicating the laws governing the rise in temperature:

$$\vartheta = \frac{H_{,,}}{S \pi r^2 l}$$

By substituting in this equation the values of $H_{,,}$ and $R_{,,}$ already given, and reducing, we may derive the following equivalent expressions for the rise in temperature:

$$\vartheta = \frac{E^2}{\left(R_{,} + \frac{\rho l}{\pi r^2}\right)^2} \times \frac{\rho T}{S \pi^2 r^4} = \frac{C^2 \rho T}{S \pi^2 r^4} \tag{58}$$

$$\vartheta = \frac{E^2 \rho T}{S (R_{,} \pi r^2 + \rho l)^2} \tag{59}$$

From equation (58) it appears that if the electromotive force be so varied as to maintain a constant current whatever be the values of r and l, the rise in temperature will be directly proportional to the specific resistance and inversely proportional to the product of the specific heat by the fourth power of the radius, and hence may be increased very rapidly by reducing the cross-section of the wire, and selecting a metal of high specific resistance and of low specific heat.

But from equation (59) it may be shown that if the generator, and hence the electromotive force, be left unchanged as we diminish the cross-section of the wire (and consequently reduce the strength of the current), the rise in temperature will be less than before by the following quantity, in which $E_{,}$ is the increment of the electromotive force which the former supposition would have required:

$$\frac{\rho T (2 E E_{,} + E_{,}^2)}{S (R_{,} \pi r^2 + \rho l)^2}$$

Since the increase of resistance, and hence the reduction of the strength of the current, is very rapid as the size of the wire is reduced, this quantity $E_{,}$ may become so large as to defeat the end in view. In other words, the rise in temperature produced by sending a current through a very fine wire may be much less than if a larger wire were chosen. For example, half a dozen large cells of Beardslee's chrome-lead battery, of which the electromotive force is low and the internal resistance excessively small, will raise 6 inches of ordinary iron telegraph wire to a white heat; when if the current be sent through the same length of very fine platinum fuze wire, the highest temperature reached may almost be borne by the hand.

It might easily be proved by an analysis similar to the above, that the same principles are applicable to *any part* of an exterior circuit consisting of wires non-homogeneous and varying in cross-section at different points. In fact, they cover the whole mathematical theory of the bridge of a low-tension fuze.

Stated in general language, the deductions from equations (58) and (59) are, then, the following: To obtain at the bridge the highest temperature possible from a given generator acting through a circuit of given length, the bridge wire should have the highest attainable specific resistance, and the lowest attainable specific heat, and should be *as short and fine* as possible; while the fuze wires and the rest of the circuit should consist of a metal having a low specific resistance and a high specific heat, and should also have a large cross-section. By fulfilling these conditions, we introduce the fuze with the minimum reduction in C; and hence approximate as closely as possible to securing the full benefit due to the fineness of the bridge wire; *i. e.*, to a gain proportional to the fourth power of the reciprocal of its radius.

One other point, however, must not be forgotten—provision should be made to reduce, so far as may be possible, the unavoidable loss of heat at the bridge by radiation, and especially by conduction. To this end, the priming should be a poor conductor; and the bridge *must have a certain length*, or the temperature at the middle point (where it is greatest) will be kept down unduly by the loss of heat passing by conduction into the fuze wires to which the ends are soldered. Instead, therefore, of making the bridge *as short as possible*, as indicated by the above discussion, it must be given sufficient length to avoid undue loss from this cause. The best length will vary with the particular bridge wire selected; and it should be determined for each variety of wire, by a special measurement which will be considered hereafter.

This discussion shows very clearly that it is rather *specific* than *absolute* resistance which is useful at the bridge; and hence, that the common expedient of throwing the wire into a long coil in order to increase the resistance and diminish the loss of heat by radiation and conduction to the priming, is vicious unless the generator has surplus electromotive force. In other words, no more bridge resistance than is actually necessary to develop sensitiveness should be admitted. With single fuzes this is of little moment; but, as will be seen hereafter, when many fuzes are to be fired simultaneously it becomes of vital importance.

The selection of the material is the first point for consideration, in applying the foregoing principles to determining the best bridge for our submarine mining service. The following table exhibits, for the common metals, the numerical values of the several constants which enter these formulæ, derived from the best authorities, viz: The specific heat from Watt's Chemistry, the heat conductivity from Balfour Stewart's tables, and the specific electrical resistance, at zero Centigrade, from Matthiessen's experiments:

Metallic constants.

Kind of metal.	Specific electrical resistance.	Specific heat.	Conductivity for heat.
Copper	1.06	0.0951	73.6
Iron	6.46	0.1138	11.9
Gold	1.37	0.0324	53.2
Silver	1.00	0.0570	100.0
Lead	13.36	0.0314	8.5
Platinum	6.02	0.0324	8.4
Tin	8.58	0.0562	14.5
Zinc	3.74	0.0955	.....
Brass	.....	0.0939	23.6
Bismuth	87.26	......	1.8
Platinum-silver (2 silver, 1 platinum)	16.22	......	.....
German silver	13.92	......	.....
Gold-silver (2 gold, 1 silver)	7.23	......	.....

Two physical properties of these metals must exert a governing influence upon the selection; (1) ductility, without which it would be difficult or impossible to draw them into very fine wire; (2) resistance to corrosion when embedded in the priming, possibly in a damp state. These conditions exclude lead, bismuth, and, in a word, all the baser metals.

Professor Abel, in a very interesting paper read before the Society of Telegraph Engineers on May 13, 1874 (too late to be of use in these researches), has given the results of certain of his experiments which confirm conclusions already reached by myself, viz: That German silver is decidedly liable to corrosion under the conditions stated above; and that platinum silver is its superior in this respect, but is difficult to draw into wire of uniform quality, possibly by reason of the tendency of the two metals to separate from each other.

Platinum-iridium, which is a natural alloy, is well known to offer considerably more resistance to the passage of electricity than platinum itself; to be easily fusible (and hence probably to have a low specific heat); and finally, to be safe against corrosion.

After various experiments with different metals and alloys (which will be detailed when discussing the subject of priming), a sample of wire was obtained from Berlin, in May, 1873, which proved to be precisely what was desired. The metal is platinum alloyed with a certain percentage of iridium; the diameter is 0.0025 inches; the weight is 0.90 grains Troy per yard; the electrical resistance is 3.25 ohms per inch. This wire has been definitely adopted for our service; and a supply is now on hand amply sufficient to provide for future contingencies.

It only remains to explain the method adopted (February, 1875) for finally establishing the exact length of the bridge in accordance with the principles already laid down.

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The apparatus and general method of operating were those already described under the head of elaborate testing. In place of the fuze was inserted the following device:

Two brass clips were so attached to a base-board that the distance between them could be accurately regulated. The jaws could be opened and shut by screws, and they were so carefully fitted to each other as to firmly clamp even the fine wire to be tested. Their size was sufficient to exaggerate the loss of heat by conduction, which is always caused by the fuze wires. These clips were first set at the desired distance apart; one end of the fine wire was next secured in its jaw; the wire was then passed through the other jaw, drawn tightly, and finally clamped in its true position. By this plan different known lengths of the wire were successively submitted to the action of the current under conditions analogous to those of the bridge of a fuze.

To determine when the temperature, rising under the influence of the regularly increasing current of electricity, reached certain standard points, compressed gun-cotton was pulverized and pressed upon the fine wire. Its flashing determined the first observation. The wire was then carefully watched, and when it first changed color to a faint red, the second record was taken. Lastly, the current was noted when after passing through the red and white stages the wire finally deflagrated.

The following table exhibits the results obtained by this method with the standard wire adopted for our service—each figure being the mean of two measurements. The differences between them were so slight in every case that although a few trifling discrepancies are observable in the means, it appeared to be a needless labor to accumulate more data.

Tests of standard fuze wire.

Length of bridge in thirty-seconds of an inch.	Resistance in ohms.				Current in webers.		
	Cold.	Gun-cotton flashes.	Faint red color.	Deflagrates.	Gun-cotton flashes.	Faint red color.	Deflagrates.
2	0.25	0.28	0.31	0.39	0.83	1.10	1,77
4	0.50	0.53	0.59	0.76	0.48	0.69	1.18
6	0.68	0.74	0.82	1.05	0.43	0.61	1.01
8	0.86	0.89	1.00	1.32	0.41	0.53	0.98
12	1.22	1.36	1.58	2.05	0.36	0.53	0.94
16	1.72	1.82	2.08	2.91	0.35	0.52	0.95
20	2.15	2.27	2.66	3.51	0.40	0.55	0.98
24	2.76	3.00	3.33	4.50	0.35	0.50	0.89
28	3.09	3.22	3.77	5.08	0.33	0.52	0.92
32	3.30	3.42	4.10	5.67	0.28	0.50	0.90
36	3.80	4.00	4.75	6.09	0.33	0.51	0.84

The curves on Plate XXII, Fig. 2, present this material in a form more easy to analyze. It is plain that until the length of the wire is increased to about $\frac{3}{16}$ of an inch, the rise in temperature at the middle (hottest) point is greatly reduced by the loss of the heat which escapes by conduction into the clips; while above that point the gain caused by lengthening the bridge is trifling in comparison with the loss entailed by the corresponding increase of resistance. The proper length, therefore, lies between $\frac{3}{16}$ and $\frac{4}{16}$ of an inch, and $\frac{7}{32}$ of an inch has been adopted. The increase of resistance due to the heating of the bridge when of this length is only about 0.05, 0.14, and 0.42 ohms, respectively, at the three standard temperatures, and hence is no serious detriment.

The Priming around the Bridge.—Systematic trials to decide upon the best priming for our service fuzes were conducted in October, 1872.

A rather coarse platinum wire, having a resistance of about 1.2 ohms per inch, was selected; and several fuzes were carefully prepared to be as nearly identical as possible except in the matter of priming. The current needful to cause explosion, the true gauge of the relative merits of the several compositions as to sensitiveness and uniformity, was then measured. Those primings which offered the best indications were again used in similar fuzes made of a finer wire, 0.002 inches in diameter and having a resistance of 2.2 ohms per inch. The following table exhibits the results of these experiments:

Comparative tests of primings.

Kind of priming.	Coarse platinum bridge 0.2 inches long (fuze resistance 0.28 ohms).				Fine platinum bridge 0.2 inches long (fuze resistance 0.48 ohms).			
	Number of fuzes.	Greatest current.	Least current.	Mean current.	Number of fuzes.	Greatest current.	Least current.	Mean current.
		Webers.	*Webers.*	*Webers.*		*Webers.*	*Webers.*	*Webers.*
Mealed powder	12	1.37	0.71	1.12	....	....	....	....
Equal parts of sulphuret of antimony and potassium chlorate	5	1.14	1.03	1.09	....	....	....	....
Safety compound, Oriental Powder Company	5	1.14	1.00	1.07	....	....	....	....
Equal parts fulminate of mercury and potassium chlorate	5	0.90	0.84	0.88	....	....	....	....
Gun-cotton in fine dust	5	0.88	0.74	0.80	15	0.56	0.39	0.48
Fulminate of mercury	6	0.78	0.70	0.75	15	0.62	0.49	0.55

The finer sample of wire was then passed between delicate rollers so as to flatten and elongate it, thus reducing its size and increasing its resistance to 3 13 ohms per inch, and the experiments were continued with the following result:

Priming, gun-cotton in fine dust; number of fuzes, 15; greatest current, 0.40 webers; least current, 0.28 webers; mean current, 0.34 webers.

Priming, fulminate of mercury; number of fuzes, 30; greatest current, 0.77 webers; least current, 0,33 webers; mean current, 0.52 webers.

These tests, although not sufficiently numerous to determine precisely the rela-

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FIG. 1. PLATINUM FUZE TESTING.

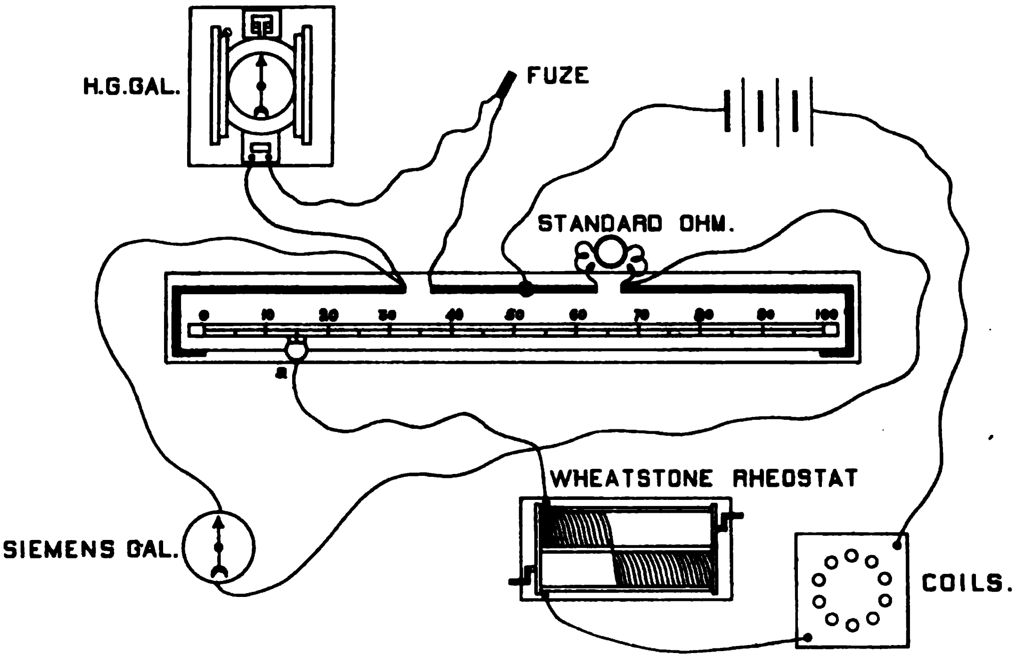
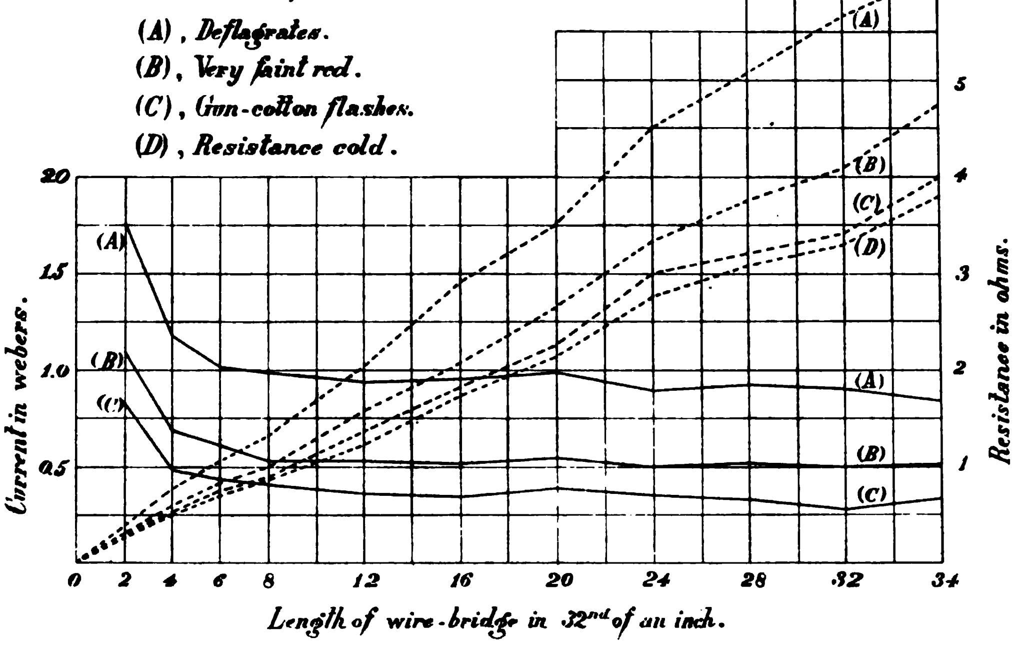


FIG. 2. STANDARD WIRE TESTS.

Full lines denote current; dotted, resistance.



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tive sensitiveness of the several primings, were regarded as enough to confine the choice to gun-cotton and fulminate of mercury.

Experimental fuzes, primed with each of those substances, were accordingly prepared and tested in large numbers and in various ways. After extended experience, fulminate of mercury was finally adopted, for the following reasons:

Permanency, uniformity, and ignition at a low temperature are the three essential requisites. The first may be conceded to both substances, if properly prepared and confined in an air-tight and well-devised fuze plug.

In respect to uniformity, fulminate of mercury has decidedly the advantage, because being a heavy powder it can be packed more easily and certainly around the wire. While not a single instance of failure has been recorded among the thousands of fulminate of mercury fuzes used in these investigations, several gun-cotton fuzes have failed by the deflagration of the wire without the ignition of the gun-cotton priming. This possibility is noted by Professor Abel in his paper above mentioned· The cause is evidently defective packing—which is not easy to regulate with so light a substance. The same difficulty is indicated by a wider range in the current requisite for ignition.

As to temperature of ignition, gun-cotton flashes at 428° Fahr. and fulminate of mercury at 392° Fahr. (Champion); but this advantage of the latter is reversed in practice, because fulminate of mercury being a better conductor of heat lowers the temperature of the bridge more rapidly, and hence requires a slightly stronger current—as shown by the foregoing tables. For certain special uses, such for example as blasting on a large scale, this fact may properly give the preference to gun-cotton, especially if pulverized and mixed with enough mealed powder to make it pack readily, as suggested by Professor Abel, or in the wisp form and soaked with collodion to give it stickiness, as recommended by other authorities.

If the fuzes are to be kept a long time in store, the former plan, substituting fulminate of mercury for mealed powder, is considered to be the better of the two; for it is hardly possible to so perfectly remove all traces of acid from long staple gun-cotton as to be certain that it may not undergo chemical change.

Fuzes for the Engineer Service.—Excessive sensitiveness is by no means desirable in a fuze designed for submarine mining, because it should carry without dangerous rise in temperature such currents as are requisite for determinate testing and for operating the automatic apparatus. Experiments at Willets Point prove that the proper limit can easily be reached, and even exceeded, with fulminate of mercury as the sole priming; and as this ensures absolute certainty of ignition, it has determined the choice for our service fuzes.

This limit may be established by the following considerations: To conveniently operate the automatic system, and to permit easy and safe testing, a maximum current of about 0.15 webers should be admitted. The rise in temperature at the bridge, under the conditions usual in firing submarine mines, has already been shown to be nearly proportional to the square of the current. Hence, adopting 10 as the coefficient of safety to allow for carelessness, anomalous sensitiveness in the fuzes, etc., the firing current should be about:

$$\sqrt{10 \times (0.15)^2} = 0.47 \text{ webers.}$$

The general internal arrangements of the pattern of fuze adopted for our service have already been explained on page 180.

To prevent possibility of deterioration or failure, all fuzes should be soldered with resin as a flux; and a solder which melts only at a high temperature must always be selected.

Before attempting to unite the platinum to the fuze wires, their ends should be slightly notched; attached to the plug; well tinned; and, finally, gauged to the exact length of the bridge. It is then easy with the aid of a spirit-lamp to secure a perfect union of the two metals, and a uniform electrical resistance. The ends of the fuze wires must next be slightly bent toward each other, in order to relieve the platinum from any possible strain even if the wood should change its form by warping or shrinking. The plug is then ready for insertion in the cap, and for the other operations already described.

The following table exhibits tests of fuzes prepared with the standard wire and fulminate of mercury, at various dates and by different persons. Many of the samples were experimental, and they therefore do not give a true idea of the uniformity as to resistance and igniting current which is characteristic of our adopted pattern. They are reported to show how easy it is to secure a narrow range in the latter quality, even when no extraordinary care is taken in the manufacture. This is well illustrated in the measurement of June, 1879, where by reason of bad soldering the resistances were entirely anomalous without apparently affecting the current required for ignition. Indeed, the importance of securing absolute uniformity in electrical resistance is often overrated, as is evident from the table on page 231. The true object of measuring the resistance of a fuze before use, is to detect such defects of manufacture as bad soldering and accidental shunts—which might seriously modify the strength of current required for ignition. A slight variation in the length of the bridge hardly affects this quantity, if a standard length has been selected at a safe distance from the point of abrupt curvature in the current curve shown by Fig. 2, Plate XXII:

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Standard wire and fulminate of mercury.

Fuzes made and tested.	Length of bridge.	Number tested.	Values.	Resistance of fuze.			Strength of current.	Remarks.
				Cold.	Exploded.	Increase.		
	Inches.			*Ohms.*	*Ohms.*	*Ohms.*	*Webers.*	
June, 1873	0.25	10	Maximum ...	0.84	....	....	0.51	
			Minimum ...	0.63	....	....	0.36	
			Mean	0.70	....	....	0.42	
June, 1873.......	0.25	8	Maximum ...	0.87	....	....	0.54	
			Minimum ...	0.73	....	....	0.27	
			Mean	0.79	....	....	0.41	
February, 1874 ..	0.25	7	Maximum ...	0.93	1.05	0.15	0.45	
			Minimum ...	0.60	0.70	0.05	0.40	
			Mean	0.72	0.82	0.10	0.43	
May, 1874	0.25	8	Maximum ...	0.74	0.82	0.10	0.48	
			Minimum ...	0.63	0.67	0.04	0.31	
			Mean	0.70	0.77	0.07	0.41	
June, 1873.......	0.20	9	Maximum ...	0.70	....	....	0.61	Wire flattened, as explained.
			Minimum ...	0.28	....	....	0.37	
			Mean	0.49	....	....	0.48	
April, 1874	0.20	10	Maximum ...	0.53	0.80	0.27	0.59	
			Minimum ...	0.30	0.43	0.13	0.47	
			Mean	0.40	0.59	0.19	0.52	
May, 1874	0.20	10	Maximum ...	0.76	0.86	0.10	0.52	
			Minimum ...	0.55	0.61	0.05	0.45	
			Mean	0.61	0.68	0.07	0.49	
July, 1874.......	0.20	10	Maximum ...	0.87	0.96	0.09	0.52	
			Minimum ...	0.70	0.74	0.06	0.48	
			Mean	0.79	0.86	0.07	0.50	
February, 1876 ..	0.20	3	Maximum ...	0.78	0.90	0.12	0.48	
			Minimum ...	0.72	0.80	0.08	0.40	
			Mean	0.75	0.85	0.10	0.44	
June, 1879	0.20	20	Maximum ...	2.27	1.64	0.42	0.55	Badly soldered—rejected.
			Minimum ...	0.69	0.76	−0.70	0.42	
			Mean	0.88	1.00	0.12	0.49	
December, 1879 .	0.22	18	Maximum ...	0.77	0.86	0.09	0.57	
			Minimum ...	0.42	0.59	0.17	0.51	
			Mean	0.56	0.66	0.10	0.54	
January, 1880 ...	0.22	20	Maximum ...	0.70	0.79	0.09	0.55	
			Minimum ...	0.58	0.65	0.07	0.43	
			Mean	0.62	0.70	0.08	0.46	
March, 1880	0.22	37	Maximum ...	0.90	1.00	0.12	0.56	
			Minimum ...	0.49	0.55	0.06	0.41	
			Mean	0.69	0.77	0.08	0.48	
October, 1880....	0.22	10	Maximum ...	0.76	0.87	0.11	0.50	
			Minimum ...	0.59	0.67	0.07	0.45	
			Mean	0.67	0.76	0.09	0.48	

The following table gives a fair idea of the degree of uniformity exacted in the tests, before accepting a lot of fuzes. The sample was an ordinary one, and the fuzes were taken at random from four different boxes. The standard resistance, when cold, is 0.7 of an ohm; and the current, 0.47 webers:

Test of fuzes for the submarine mining service.

Number of test.	Current through galvanometer.	Resistance in ohms.			Current in webers.	Remarks.
		Cold.	At explosion.	Increase.		
1	Direct	0.63	0.71	0.08	0.48	This sample was made to order by G. A. Goodyear, in March, 1880, using the service platinum-iridium wire, with fulminate of mercury as the sole priming.
2	....do	0.65	0.73	0.08	0.50	
3	....do	0.65	0.73	0.08	0.47	
4	....do	0.49	0.55	0.06	0.48	
5	....do	0.75	0.84	0.09	0.47	
6	Reversed	0.74	0.85	0.11	0.49	
7	....do	0.65	0.73	0.08	0.48	
8	....do	0.62	0.69	0.07	0.47	
9	....do	0.67	0.75	0.08	0.49	
10	....do	0.61	0.69	0.08	0.56	
11	....do	0.63	0.71	0.08	0.51	
12	....do	0.67	0.73	0.06	0.47	
13	....do	0.86	0.95	0.09	0.47	
14	....do	0.63	0.70	0.07	0.47	
15	....do	0.70	0.77	0.07	0.49	
16	Direct	0.82	0.89	0.07	0.46	
17	....do	0.65	0.74	0.09	0.44	
18	....do	0.69	0.77	0.08	0.46	
19	....do	0.67	0.76	0.09	0.48	
20	....do	0.60	0.72	0.12	0.50	
Means		0.67	0.75	0.08	0.48	

If the needs of the Torpedo Service alone were concerned, the foregoing discussion would cover the whole subject; but it is often desirable in the civil works conducted by the Corps of Engineers to make use of low-tension fuzes under circumstances which require many to be fired simultaneously, and in which extreme sensitiveness is, therefore, a desideratum.

It will soon be shown, when considering the problem of simultaneous ignitions, that the number of fuzes connected in series which should form a single group—and hence the total number of possible ignitions with a given generator of electricity—is inversely proportional to the resistance in ohms of one of these fuzes at the instant of explosion. The immense importance of considering this element, as well as the absolute sensitiveness of the bridge and priming to the current, is therefore apparent. It sufficiently explains why a short bridge has been preferred to the long one thrown into a small coil, which appears to be the favorite with some foreign engineers.

The following table exhibits trials conducted to obtain extreme sensitiveness—the last five being tests of fuzes prepared by General Newton for his great blast at Hallett's Point in 1876.

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Sensitive low-tension fuzes.

Number tested.	The wire bridge.			Priming.	Values.	Resistance of fuze.			Strength of current.	Remarks.
	Metal.	Length.	Diameter.			Cold.	Explodes.	Increase.		
		Inches.	*Inches.*			*Ohms.*	*Ohms.*	*Ohms.*	*Webers.*	
3	German silver	0.20	0.0020	Fulminate of mercury.	Max	0.90	....	....	0.43	Made by Smith.
					Min	0.69	....	....	0.37	
					Mean	**0.79**	....	....	**0.39**	
10	GOLD-IRON. 6 iron .... 95 gold	0.20	0.0020	Fulminate of mercury.	Max	2.04	2.14	0.06	0.35	Made by Goodyear.
					Min	1.67	1.74	0.14	0.31	
					Mean	**1.87**	**1.97**	**0.10**	**0.32**	
5	PLAT.-SILVER. 1 platinum..... 2 silver	0.20	0.0015	Fulminate of mercury.	Max	3.08	3.29	0.31	0.34	Made by Goodyear.
					Min	2.58	2.75	0.17	0.29	
					Mean	**2.88**	**3.09**	**0.21**	**0.31**	
10	1 platinum* .... 2 silver	0.20	0.0015	Pulverized gun-cotton.	Max	1.63	1.70	0.27	0.35	Made by Striedinger.
					Min	1.33	1.45	0.07	0.25	
					Mean	**1.43**	**1.56**	**0.13**	**0.30**	
6	1 platinum† .... 2 silver	0.20	0.0015	Pulverized gun-cotton.	Max	1.49	1.59	0.15	0.31	Goodyear pattern.
					Min	1.30	1.35	0.03	0.22	
					Mean	**1.41**	**1.47**	**0.06**	**0.25**	
6	1 platinum..... 2 silver	0.20	0.0015	Fulminate of mercury.	Max	1.58	1.66	0.10	0.35	Goodyear pattern.
					Min	1.36	1.41	0.06	0.32	
					Mean	**1.49**	**1.57**	**0.08**	**0.33**	
10	1 platinum.... 2 silver	0.25	0.0015	Fulminate of mercury.	Max	2.11	2.21	0.13	0.30	Made by Laflin & Rand, and used at the Hallett's Point explosion.
					Min	1.76	1.83	0.07	0.26	
					Mean	**1.90**	**2.01**	**0.11**	**0.28**	

* Bridge deflagrates at 0.45 webers; resistance 2.19 ohms.

† Bridge deflagrates at 0.54 webers; resistance 1.87 ohms.

Foreign and American Fuzes.—As already seen, the principle upon which low-tension fuzes are exploded allows a wide range in sensitiveness; and a pattern specially adapted for any particular service can readily be prepared. This fact renders an extended trial of foreign and other fuzes of this class of comparatively little importance; but as it was undertaken, the electrical results will be reported in a tabular form. The mechanical details can best be studied by examining the samples in the Torpedo Museum at Willets Point.

Tests of foreign and American fuzes.

Designation.	No. tested.	Values.	Resistance in ohms.			Current in webers.	Remarks.
			Cold.	Explodes.	Increase.		
ENGLISH. Abel (1872)	13	Maximum ...	0.09	0.09	0.03	3.68	Bridge, 0.25 inches long and 0.007 in diameter. Priming, wisp gun-cotton and gunpowder.
		Minimum ...	0.03	0.05	0.00	3.16	
		Mean	**0.04**	**0.06**	**0.02**	**3.43**	
McEvoy (1873)	5	Maximum ...	0.35	0.48	0.13	1.09	Bridge, 0.25 inches long and 0.003 in diameter. Priming, mealed powder.
		Minimum ...	0.13	0.25	0.01	0.97	
		Mean	**0.23**	**0.32**	**0.09**	**1.03**	

Tests of foreign and American fuzes—Continued.

Designation.	No. tested.	Values.	Resistance in ohms.			Current in webers.	Remarks.
			Cold.	Explodes.	Increase.		
Silvertown (1874)	11	Maximum	0.43	0.59	0.20	0.70	Bridge, 0.25 inches long and 0.003 in diameter. Priming, wisp gun-cotton and gunpowder.
		Minimum	0.27	0.33	0.06	0.45	
		Mean	**0.36**	**0.47**	**0.11**	**0.58**	
FRENCH.							
Ruhmkorff (1875)*	10	Maximum	0.60	1.02	0.68	0.59	Bridge, 0.12 inches long and 0.0015 in diameter. Priming, wisp gun-cotton and gunpowder.
		Minimum	0.30	0.57	0.21	0.37	
		Mean	**0.44**	**0.82**	**0.38**	**0.49**	
Digney (1874)	10	Maximum	3.28	4.70	1.88	0.26	Bridge, 1.0 inches long and 0.0015 in diameter. Priming, wisp gun-cotton.
		Minimum	1.48	2.39	0.32	0.14	
		Mean	**2.38**	**3.48**	**1.10**	**0.18**	
Breguet (1873)	1	Maximum	0.81	1.14	0.33	0.41	Bridge (spiral), 1.0 inches long and 0.003 in diameter. Priming, wisp gun-cotton.
		Minimum	0.81	1.14	0.33	0.41	
		Mean	**0.81**	**1.14**	**0.33**	**0.41**	
Breguet (1874)	1	Maximum	4.15	5.69	1.54	0.13	Bridge (spiral), 0.37 inches long and 0.0008 in diameter. Priming, wisp gun-cotton.
		Minimum	4.15	5.69	1.54	0.13	
		Mean	**4.15**	**5.69**	**1.54**	**0.13**	
Gaiffe (1880)†	20	Maximum	0.41	0.90	0.51	0.75	Bridge, 0.16 inches long and 0.0015 in diameter. Priming, gun-cotton wisp.
		Minimum	0.19	0.39	0.19	0.49	
		Mean	**0.31**	**0.61**	**0.30**	**0.60**	
GERMAN.							
Siemens & Halske (1874)‡	10	Maximum	2.95	2.65	+ 0.37	0.30	Bridge (not soldered), 0.25 inches long and 0.0015 in diameter. Priming, wisp gun-cotton.
		Minimum	2.05	2.17	− 0.78	0.22	
		Mean	**2.34**	**2.40**	**0.06**	**0.25**	
AMERICAN.							
Chester (1872)	18	Maximum	1.10	1.48	0.65	0.90	Bridge (platinum foil), 0.62 inches long and 0.0005 and 0.006 in diameter. Priming, fulminate of mercury.
		Minimum	0.27	0.49	0.22	0.44	
		Mean	**0.61**	**1.09**	**0.48**	**0.66**	
Chester (1872)	4	Maximum	5.30	....	....	0.78	Bridge like last, but unsoldered. Priming, mealed powder.
		Minimum	1.00	....	....	0.70	
		Mean	**2.20**	....	....	**0.73**	
Same (tested in 1879)	5	Maximum	12.10	3.16	− 10.47	0.93	Identical with last—showing oxidation of bridge contacts.
		Minimum	3.09	1.63	− 1.16	0.70	
		Mean	**8.07**	**2.11**	**− 5.97**	**0.84**	
Stowell (1873)	15	Maximum	0.39	0.74	0.35	1.16	Bridge (german silver), 0.25 inches long and 0.0025 in diameter. Priming, mealed powder.
		Minimum	0.31	0.59	0.26	0.64	
		Mean	**0.34**	**0.65**	**0.31**	**0.97**	
Stowell (1873)	10	Maximum	0.38	0.68	0.38	1.06	Bridge, like last. Priming, wisp gun-cotton.
		Minimum	0.26	0.48	0.19	0.62	
		Mean	**0.33**	**0.57**	**0.24**	**0.77**	
Goodyear (1874)	9	Maximum	0.49	0.75	0.33	0.38	Bridge, 0.20 inches long and 0.0015 in diameter. Priming, wisp gun-cotton and fulminate of mercury.
		Minimum	0.39	0.50	0.10	0.31	
		Mean	**0.44**	**0.59**	**0.15**	**0.34**	
Goodyear (1880)	6	Maximum	0.39	0.66	0.27	0.52	Bridge, 0.22 inches long and 0.003 in diameter. Priming, not noted.
		Minimum	0.36	0.57	0.21	0.50	
		Mean	**0.37**	**0.61**	**0.24**	**0.51**	
Laflin & Rand (1876)	10	Maximum	0.33	0.59	0.26	1.06	Bridge, 0.12 inches long and 0.002 in diameter. Priming, pulverized gun-cotton and fulminate of mercury.
		Minimum	0.21	0.40	0.18	0.83	
		Mean	**0.25**	**0.47**	**0.22**	**0.98**	

* Bridge deflagrates with 0.68 webers; resistance 2.25 ohms.

† Bridge deflagrates with 0.80 webers; resistance 1.16 ohms.

‡ Bridge deflagrates with 0.42 webers; resistance 3.71 ohms.

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Tests of foreign and American fuzes—Continued.

Designation.	No. tested.	Values.	Resistance in ohms. Cold.	Resistance in ohms. Explodes.	Resistance in ohms. Increase.	Current in webers.	Remarks.
Laflin & Rand (1880)	10	Maximum	0.36	0.47	0.11	0.67	Bridge, 0.25 inches long and 0.002 in diameter. Priming, 3 parts fulminate of mercury and 1 part potass. chlorate.
		Minimum	0.31	0.41	0.08	0.58	
		Mean	**0.34**	**0.44**	**0.10**	**0.62**	
Lieut. Bradford, U. S. N. (1873)	4	Maximum	0.57	....	....	0.65	Bridge, 0.20 inches long and 0.002 in diameter. Priming, fulminate of mercury.
		Minimum	0.43	....	....	0.57	
		Mean	**0.51**	....	....	**0.61**	
Lieut. Bradford, U. S. N. (1873)	5	Maximum	0.82	1.03	0.22	0.43	Bridge, 0.38 inches long and 0.002 in diameter. Priming, wisp gun-cotton and fulminate of mercury.
		Minimum	0.77	0.97	0.19	0.41	
		Mean	**0.79**	**0.99**	**0.20**	**0.42**	
Lieut. Bradford, U. S. N. (1873)	4	Maximum	0.54	0.69	0.17	0.50	Bridge, 0.20 inches long and 0.002 in diameter. Priming, wisp gun-cotton and fulminate of mercury.
		Minimum	0.48	0.61	0.12	0.47	
		Mean	**0.52**	**0.66**	**0.14**	**0.49**	
Professor Hill (1874)	10	Maximum	0.33	0.41	0.08	0.58	Bridge, 0.20 inches long and 0.0025 in diameter. Priming, wisp gun-cotton and fulminate of mercury.
		Minimum	0.28	0.35	0.05	0.46	
		Mean	**0.31**	**0.38**	**0.07**	**0.51**	
Cannon primers, Major Whittemore, Ordnance Department (1876).	8	Maximum	0.69	1.42	0.74	0.65	Bridge, 1.0 inches long and 0.003 in diameter. Priming, wisp gun-cotton and mealed powder.
		Minimum	0.57	0.99	0.40	0.54	
		Mean	**0.64**	**1.15**	**0.51**	**0.59**	
Cannon primers, Frankford Arsenal, Ordnance Department (1879).	10	Maximum	1.18	2.05	0.88	0.85	Bridge, 0.81 inches long and 0.003 in diameter. Priming, wisp gun-cotton and fine gunpowder.
		Minimum	0.91	1.19	0.28	0.49	
		Mean	**1.06**	**1.61**	**0.55**	**0.64**	
Cannon primers, U. S. N. (1878)	10	Maximum	0.56	0.60	0.06	0.67	Bridge, 0.12 inches long and 0.0015 in diameter. Priming, wisp gun-cotton and gunpowder.
		Minimum	0.50	0.56	0.03	0.52	
		Mean	**0.53**	**0.58**	**0.05**	**0.57**	

A study of this table shows that the English fuzes, as a class, are by no means sensitive, and that the French fuzes are exceptionally so

The German fuze is inferior in all its mechanical details, and particularly in the neglect to solder the bridge to the conducting wires. This peculiarity causes extraordinary and irregular variation in the resistance, as the bridge becomes gradually heated—an effect probably due to the expansion of the wire, which changes the resistance at the points of contact

The same defect exists in Chester's American fuzes (gunpowder) as first made by him; and the second test, after a lapse of some years, indicates that great deterioration is liable to occur from the oxidation rendered possible by this vicious practice. His fulminate of mercury fuzes, at my suggestion, were soldered; and although half of the tests above reported were made in 1872, and the rest in 1879, they indicate no change whatever in the sample. His foil, however, is inferior to fine wire; both in sensitiveness and in the excessive increase of resistance caused by the current.

As a class, our American fuzes are believed to be inferior to those of no other nation, for civil or military purposes. The pattern adopted by the Navy for cannon is worthy of special attention; the primer is introduced through the vent, and rests on the cartridge in a manner which renders a miss-fire nearly impossible.

The foregoing analysis places in a strong light the superiority of low-tension fuzes to high and medium tension fuzes, for use in submarine mining. They admit, at any time, of individual tests to determine in advance their perfect condition; they are suited to electricity in the form most easily controlled, viz: when the potential is row; they are entirely exempt from danger of accidental ignition by the inductive action of currents in a neighboring conductor; and, lastly, they may be prepared of any desired degree of sensitiveness, according to the use for which they are needed.

The Service Cut-Off.—It may often happen that a single electrical conductor connects more than one mine with the operating apparatus at the shore station. If one of such a group be exploded, the bared end of its branch cable, left in the water, will make sufficiently good earth to interfere with the automatic firing of the rest. To obviate this difficulty, use is made of a device termed a cut-off.

This name is applied to a peculiar pattern of low-tension fuze which forms part of the electrical circuit in the branch cable, and by a simultaneous rupture breaks its continuity when the mine is fired. Being enclosed in a water-tight box, this second rupture of the conductor leaves the end next to the shore insulated; and hence accomplishes the object intended.

Certain foreign cut-offs were first tested, acting on one of two principles: (1) the use of a firing current strong enough to deflagrate a fine platinum wire, similar to the bridge of the fuze, either simultaneously with the latter, or shortly after it has exploded; (2) the igniting of a wisp of gun-cotton attached to the fine wire, causing enough gas to be formed to remove a small wooden cap, and thus mechanically break the wire. Neither of these plans proved to be satisfactory, as will now be explained.

To test the first plan a circuit was arranged (February, 1875,) as follows: A powerful Grove battery was coupled in series, and the terminals were connected through a set of resistance coils, a tangent galvanometer, a key for closing the circuit at will, a service fuze, and an unprimed cut-off having a fine wire bridge like that of the fuze.

The fuze and cut-off were at first omitted; and the current was regulated by varying the resistance unplugged in the coils until the galvanometer indicated the strength desired; they were then inserted, and their known resistance at explosion was subtracted from the amount unplugged. When the circuit was again closed a known current was thus sent through the fuze and cut-off and its effect was noted.

The normal current to fire the fuze was 0.45 webers; but even 3 webers often failed to deflagrate the cut-off simultaneously, although 1 weber would sever its wire if applied for a sensible time.

This result was confirmed by experiments upon two cut-offs of fine platinum-silver wire, $\frac{3}{16}$ inches long and 0.0015 in diameter, with no fuze in circuit. Although

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0.58 webers would deflagrate one of them, 2.7 webers failed to rupture both—the parting of one always saving the other.

An attempt was made to slightly retard the fuze explosion by using two in derived circuit; but no practical result was reached.

Hence, I concluded, that a cut-off arranged on this plan would be very uncertain. The bridge of the fuze is surrounded with a priming which ignites even before the reddening of the wire; and unless an enormous current traverses the circuit, the explosion, and hence the first rupture, occurs before the bridge of the cut-off can deflagrate. But the resistance of the end of the cable left exposed by the detonation of the mine, is usually high—often a couple of hundred ohms; and a firing battery of inconvenient and unnecessary size would be required to deflagrate the bridge of the cut-off through such a resistance. Hence there might be no second rupture, either at the same time or after the first. This plan was accordingly rejected.

The second plan—breaking the bridge of the cut-off mechanically, by a cap removed by the burning of a wisp of gun-cotton—proved to be objectionable on several grounds. Being rather more sensitive to the current than a fuze primed with fulminate of mercury, the arrangement would sometimes act first, and thus prevent the explosion of the latter entirely. The form of this device, as used in Europe, was bulky and therefore ill suited to our purposes. When made of ebonite it proved to be too brittle; and when of iron, the joint sometimes leaked, and, by admitting water, caused trouble after the mine was planted. Some of these objections might have been removed by remodelling the mechanism; but experience convinced me that the principle was faulty, and it was accordingly rejected.

Considered as a problem in heat and electricity, the best solution seemed to me to depend upon the following principles. To produce simultaneous rupture at two different points of the same circuit, under the simplest conditions, these points should be physically similar; *i. e.*, the cut-off and fuze should have the same kind of bridge and the same kind of priming. When prepared with care the range of variation in these quantities may be made very slight; but since it cannot be absolutely eliminated, the influence of residual differences must be neutralized. Time is the only element under control which can be varied to effect this object. Experiment proves that when the minimum current required for igniting a fuze is passed through the bridge, the rise in temperature occurs gradually, and a very sensible time elapses before it becomes hot enough to ignite the priming; also, that as the current is increased this time is diminished. Even after the requisite temperature is reached, time is still required to perform the mechanical work of explosion. If, therefore, *by increasing the current within reasonable limits, the time needed to raise the temperature of the bridge to the requisite degree can be made less than the minimum required to perform the mechanical work of explosion,* the problem admits of a satisfactory and certain solution.

Whether this theoretical result could be reached in practice could only be determined by experiment, and the work was undertaken in 1875. The apparatus and method employed were those described above when discussing the simple wire cut-off.

The results obtained in this series of experiments proved to be of much practical importance, since they formed the basis of the general theory for simultaneous ignitions soon to be considered. This theory rarely finds application in submarine mining, except in the special case of the cut-off; but in military demolitions, and in many civil works of the Corps, its use is so frequent that these researches are reported in detail in the following table.

To experiment upon only two fuzes at once would have involved needless labor, since if the theory be true it should be applicable to any number of fuzes in the same circuit. A battery consisting of forty large Grove cells, or its equivalent, was accordingly employed in some of the trials, and the number of fuzes successfully fired in a single circuit sometimes exceeded thirty.

Two kinds of fuze were used—those marked A were made of the service wire, bridge ¼ inch long and 0.0025 in diameter; priming, fulminate of mercury; current to explode a single fuze, 0.45 webers; current to deflagrate bridge, 1.03 webers. Those marked B were made of platinum silver wire, bridge ¼ inch long and 0.0015 in diameter; priming, fulminate of mercury; current to explode a single fuze, 0.28 webers; current to deflagrate bridge, 0.55 webers.

Experiments upon fuzes united in series.

Number of experiment.	Current in webers.	Low-tension fuzes.			Number of experiment.	Current in webers.	Low-tension fuzes.		
		Kind.	Number in series.	Number of failures.			Kind.	Number in series.	Number of failures.
1	0.85	A	9	1	21	1.23	A	5	0
2	0.86	A	10	9	22	1.23	A	2	0
3	0.88	A	13	7	23	1.23	A	2	1
4	0.88	A	5	1	24	1.23	A	2	1
5	0.89	A	10	6	25	1.27	A	5	0
6	0.89	A	5	1	26	1.33	A	30	0
7	0.92	A	2	1	27	1.34	A	5	0
8	0.93	A	10	7	28	1.34	A	10	0
9	1.00	A	17	10	29	1.34	A	10	0
10	1.06	A	2	1	30	1.35	A	2	1
11	1.06	A	2	1	31	1.37	A	2	0
12	1.06	A	2	0	32	1.37	A	2	0
13	1.08	A	7	0	33	1.37	A	2	0
14	1.09	A	5	0	34	1.37	A	2	0
15	1.11	A	2	0	35	1.37	A	2	0
16	1.11	A	2	1	36	1.37	A	2	0
17	1.11	A	2	1	37	1.37	A	2	0
18	1.18	A	10	0	38	1.37	A	2	0
19	1.23	A	5	0	39	1.37	A	2	0
20	1.23	A	5	0	40	1.37	A	2	1

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Experiments upon fuzes united in series—Continued.

Number of experiment.	Current in webers.	Low-tension fuzes.			Number of experiment.	Current in webers.	Low-tension fuzes.		
		Kind.	Number in series.	Number of failures.			Kind.	Number in series.	Number of failures.
41	1.42	A	5	0	67	1.86	A	10	0
42	1.45	A	30	0	68	1.86	A	10	0
43	1.48	A	5	0	69	1.86	A	10	0
44	1.49	A	10	0	70	1.86	A	10	0
45	1.49	A	35	1	71	1.88	A	20	0
46	1.50	A	20	0	72	1.89	A	20	0
47	1.53	A	2	0	73	1.91	A	20	0
48	1.53	A	2	0	74	1.96	A	20	0
49	1.53	A	2	0	75	2.02	A	20	0
50	1.53	A	2	0	76	2.20	A	5	0
51	1.53	A	2	0	77	0.41	B	3	2
52	1.53	A	2	0	78	0.48	B	3	2
53	1.79	A	2	0	79	0.49	B	3	0
54	1.79	A	2	0	80	0.49	B	3	2
55	1.79	A	2	0	81	0.54	B	3	1
56	1.79	A	2	0	82	0.59	B	3	0
57	1.79	A	2	0	83	0.59	B	3	0
58	1.79	A	2	0	84	0.59	B	3	0
59	1.79	A	2	0	85	0.59	B	3	2
60	1.79	A	2	0	86	0.67	B	3	0
61	1.86	A	5	0	87	0.67	B	3	0
62	1.86	A	5	0	88	0.67	B	6	0
63	1.86	A	5	0	89	0.67	B	6	0
64	1.86	A	5	0	90	0.67	B	6	0
65	1.86	A	5	0	91	0.67	B	36	0
66	1.86	A	10	0					

An examination of this table will show: (1) that when similar fuzes are united in series, the current which is strong enough to ensure the explosion of two will explode any greater number; (2) that unless a current which deflagrates the bridge be used, some fuzes are almost sure to fail from the breaking of the circuit by their neighbors; (3) that even such a current is not sufficient to render explosion absolutely certain; and (4) that, with fuzes primed with fulminate of mercury, a current somewhat less than three times the minimum required to explode a single fuze is sure to fire all in the circuit. The following table, which is simply an analysis of the last, exhibits these deductions in a form convenient for reference:

Summary of experiments upon fuzes in series.

Type A.		Type B.	
Currents varying from—	Per cent. fail.	Currents varying from—	Per cent. fail.
Webers.		*Webers.*	
0.8 to 1.0	50	0.40 to 0.45	67
1.0 to 1.2	28	0.45 to 0.50	44
1.2 to 1.3	8	0.50 to 0.55	33
1.3 to 1.4	3	0.55 to 0.60	17
1.4 to 1.5	1	0.60 to 0.65	8 (?)
1.5 & more.	0	0.67 & more.	0

Similar but less elaborate experiments upon other kinds of fuzes have uniformly confirmed these deductions; and thus have justified the train of reasoning which suggested the trials.

Our adopted form of cut-off has been prepared accordingly. It consists of a low-tension fuze identical with that used to explode the mines, except that the detonating cap is omitted and the priming chamber is closed with a stout plug. It is protected by a peculiar box, which will be described hereafter under its proper heading.

SIMULTANEOUS IGNITIONS.

To produce the maximum effect in removing obstructions, and in other similar work, both civil and military, pertaining to the duties of the Corps of Engineers, it is often desirable to cause the simultaneous explosion of many mines; or, sometimes, the simultaneous ignition of many fuzes distributed throughout the charge of one large mine. In the present state of science, this will always be effected by electricity; and the form usually preferred will be the voltaic or magneto-electric current acting upon numerous low-tension fuzes. Such fuzes may be united either in series, *i. e.*, fuze connected to fuze in a single circuit; or in derived circuits, *i. e.*, each fuze connected to both of the main leading wires; or in some combination of these two methods. The maximum number which it is possible to explode simultaneously by a given battery or magneto-electric machine, will vary according to the grouping adopted.

General Theory.—The following mathematical investigation of the laws which should govern the engineer in arranging such groups, was undertaken at the invitation of General Newton, in connection with his great blast at Hallett's Point. He adopted the formulæ in arranging his groups; and his magnificent success in exploding simultaneously 3,640 charges, on September 24, 1876, is a sufficient practical verification of the correctness of the theory. The principles are equally applicable to small and to large operations, where economy is an object. Let:

E = the available electro-motive force in volts.

$R_{,}$ = the corresponding internal resistance in ohms.

$C_{,}$ = the current in webers needful to fire one of the groups connected in series, all such groups being supposed equal in electrical resistance.

L = the resistance in ohms of the main leading wires connecting the source of electricity with the groups.

F = the resistance in ohms of each fuze at the instant of explosion. This includes the increased resistance due to the heating of the fine wire bridge, and also the resistance of the needful local connections.

N = the total number of fuzes which can be exploded simultaneously.

n = the number of fuzes connected in series to form a single group.

$\frac{N}{n}$ the number of such groups connected in derived circuit.

From well known electrical laws the following general equation for the blast can be stated, each member representing the total strength of current necessary to cause the explosion.

$$(60) \qquad \frac{N}{n} C_{,} = \frac{E}{R_{,} + L + \dfrac{nF}{\dfrac{N}{n}}}$$

Solving this equation with respect to N, and finding its first differential coefficient regarded as a function of n, we have:

$$\frac{dN}{dn} = \frac{E - 2FC_{,}n}{C_{,}(R_{,} + L)}$$

Placing the second member equal to zero, and combining the resulting equation with equation (60), we have for the conditions of the desired maximum:

$$(61) \qquad N = \frac{E^2}{4FC_{,}^2(R_{,} + L)}$$

$$(62) \qquad n = \frac{E}{2FC_{,}}$$

$$(63) \qquad \frac{N}{n} = \frac{E}{2C_{,}(R_{,} + L)}$$

As a check upon the computation, the following value of $C_{,}$ derived from equation (60), should be nearly the same as the assumed value. They probably will not be identical—since fuzes and groups cannot be subdivided, and fractions in n or $\frac{N}{n}$ must, therefore, be ignored.

$$(64) \qquad C_{,} = \frac{E}{\dfrac{N}{n}(R_{,} + L) + nF}$$

It is evident that these equations furnish a mathematical basis for a full discussion of the subject; for not only do they reveal the maximum number of simultaneous explosions which can be obtained with any particular generator of electricity, type of fuze, and kind of leading wire, but they also indicate the relative importance of the different constants, and hence point out the principles which should control the selection of apparatus and materials for any difficult blast. Of these constants, the numerical values of E and $R_{,}$ vary with the nature of the generator of electricity; those of F and $C_{,}$ depend upon the construction of the fuze; while L is fixed by the conductivity and cross-section of the metal selected for the main leading wires.

The first glance at equation (61) shows that N increases directly with E^2 and inversely with $C_{,}^2$, F, $R_{,}$, and L; hence, as the square of E and $\frac{1}{C_{,}}$ enter the formula, particular attention must be given to make these quantities as large as possible.

Again, a little consideration will reveal the extreme importance of making L disappear in these equations. This can and always should be done, either by using rods so large as to offer no sensible resistance to the current, or by causing the several groups to diverge at the poles of the battery, and increasing F accordingly. In this case equation (63) may be put under the form:

$$\frac{N}{n} = \frac{1}{2\,C_{,}} \times \frac{E}{R_{,}}$$

Now, since E and $R_{,}$ are both directly proportional to the number of elements coupled in series, this equation reveals the curious fact that when all the cells of a voltaic battery are so coupled, the proper grouping of the fuzes is quite independent of the number of cells; *i. e.*, the proper number of groups to be used in derived circuit is constant, no matter how many cells are coupled in series. Hence, so far as the number of groups is concerned, the relative merit of different types of battery is in the direct ratio of the numerical values of the quotient $\frac{E}{R_{,}}$ for a single element.

But equation (62) shows that, with any type of battery, the number of fuzes which can properly be placed in each group is directly proportional to the number of cells coupled in series; also, that the relative merit of different elements in this respect is directly proportional to their electro-motive force per cell.

This analysis makes it clear that, in choosing a battery for a large blast, it is only necessary to consider the numerical value of the ratio $\frac{E^2}{R_{,}}$ for a single cell, the cost per cell (K), and the relative convenience (economy) of manipulation (M); that is, the figure of merit for any type of battery is proportional to $\frac{E^2\,M}{R_{,}\,K}$.

For example, suppose one type of battery (A) to have an electro-motive force of 2 volts, an internal resistance of 0.2 ohms, a cost of $10 per cell, and a relative economy of manipulation denoted by 5; and a second type (B) to have for these quantities, respectively, the values 1.0 volts, 0.5 ohms, $1 and 3. Then, for relative merit:

Type (A) $\dfrac{2^2 \times 5}{0.2 \times 10.00} = 10.$

Type (B) $\dfrac{1^2 \times 3}{0.5 \times 1.00} = 6.$

That is, the more costly type would really be the more economical battery in the ratio of 10 to 6.

Another point likely to suggest itself is, how any given number of cells ought to be divided in separate circuits, and coupled in each circuit, to secure the best result. Although the statement may at first seem to be a little paradoxical, the matter is one

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simply of convenience. This is evident from a study of equation (61); for when L is eliminated, as we have seen should always be done in practice, if we denote by x the number of cells coupled in series, and by y the number coupled in multiple arc, e and $r_{,}$ referring to a single cell:

$$N = \frac{1}{4\,C_{,}^{2}\,F} \times \frac{x^2 e^2}{\frac{xr_{,}}{y}} = \frac{1}{4\,C_{,}^{2}\,F} \times \frac{e^2}{r_{,}} \times xy.$$

Hence, no change in N can be caused by any variation in the arrangement of the cells, provided only that, as required by equation (62), $\frac{xe}{2n\,F}$ be never made less than $C_{,}$. Indeed, a little reflection will show that this must be the case, since by the theory of the method the fuzes are always so grouped as to consume the maximum energy attainable from the elements; and, of course, no mere change of arrangement can generate or destroy energy. In practice, then, the number of cells to be coupled in series would be determined by the number of fuzes which could most conveniently be united in single groups; while the number of cells to be coupled for quantity would depend upon the desired number of groups in each circuit. From these conditions, in the case of very large blasts, the dividing of the battery into separate circuits to be closed simultaneously, naturally results. The general formulæ for these computations are the following, derived from equation (62) and equation (63):

$$x = \frac{2\,F\,C_{,}}{e}n$$

$$y = \frac{\frac{N}{n}\,2\,C_{,}\,xr_{,}}{xe - \frac{N}{n}\,2\,C_{,}\,L} = \frac{2\,N\,C_{,}\,r_{,}\,n\,F}{n^2\,e\,F - e\,N\,L}$$

As has already been stated, the quantity L should be made to disappear by a judicious selection and arrangement of the leading wires and connections. If this be neglected great loss of power will be unavoidable, as is apparent from the latter of these equations. Indeed, the chief reason for recognizing this quantity in framing equation (60), was to exhibit clearly the importance of making it zero.

In choosing the fuze, the quantities F and $C_{,}$ are to be considered. The conditions to be fulfilled by the former are simple, since it is only necessary that it be as small as possible consistent with securing the minimum value for $C_{,}$; and this, aside from the choice of suitable local leading wires, is a matter only to be learned by judicious experiment. The quantity $C_{,}$ has already been fully discussed when treating of the service cut-off.

There is, however, one particular case which must not be overlooked, viz: Where a simple derived circuit is arbitrarily chosen, or in other words when n is assumed to be unity. Evidently with this system of connections the most sensitive fuze will explode as soon as the minimum needful current traverses it; and by so doing it will increase the current flowing through the others, some of which in their turn may now detonate. Hence if the current, when subdivided among the different branches, everywhere equals the minimum required to fire a single fuze, an explosion will probably occur in a rattling volley like the fire of a skirmish line. To this case the general formulæ are inapplicable, since from the manner in which they have been deduced no arbitrary value can be assigned to n; use must, therefore, be made of equation (60), from which, when $n = 1$, we find:

$$N = \frac{E - F\,C_{,}}{C_{,}\,(R_{,} + L)} \tag{65}$$

In this equation the value of $C_{,}$ is independent of time—or, in other words, for type A (page 242) it is 0.45 webers, and for type B, 0.28 webers.

In like manner, if the fuzes be arbitrarily united in a single series, the general formulæ are inapplicable; but the number which can be exploded will be found from equation (60) to be:

$$n = \frac{E - C_{,}\,(R_{,} + L)}{C_{,}\,F} \tag{66}$$

This second case is not likely to mislead, because $C_{,}$ must have the value pertaining to two or more fuzes; *i. e.*, for type A it must be 1.5 webers and for type B, 0.67 webers; and, if the grouping in single series be the best, the fact will be indicated by $\frac{N}{n}$ becoming unity in the general formulæ. For the first case, however, since a different value of $C_{,}$ is used, it is always well to compare the numerical value of N in equation (65) with that in equation (61) before deciding upon the manner of grouping to be adopted. It must not be forgotten, however, that the explosions will probably be more nearly *simultaneous* if the larger current be used.

Practical Applications.—As a practical test of the foregoing theory, a trial was made with a blasting battery of nine cells, consisting of zinc and coke plates immersed in a solution of bichromate of potash containing the usual percentage of sulphuric acid. The opposed surfaces were 4½ by 4½ inches, separated ½ inch, and fuzes of the type A were used. The constants of the battery, freshly set up, had been found by careful measurement to be as follows: For electro-motive force 1.95 volts per cell, and for internal resistance 0.15 ohms per cell; the main leading wires had a resistance of 0.12 ohms; F was 1.0 ohms; and $C_{,}$ was assumed to be 1.33 webers. Under these circumstances, equations (61), (62), and (63) indicated that the best grouping would be five series of six fuzes each, giving thirty explosions, with a current through each fuze of 1.32 webers. Upon trial the whole exploded so nearly together that only one sound could be detected by the ear.

To compare this result with a simple grouping in series, use was made of equation (66); which showed that 12 fuzes could be thus exploded. As those selected fell a little below the average resistance, 13 were tried; and they all instantly detonated, the current through each fuze being 1.30 webers. On trying 17, which allowed a current of precisely 1 weber to pass, 7 exploded and 10 failed.

Lastly, equation (65) indicated that in simple derived circuit 26 fuzes could be fired, with a current through each fuze of 0.4[illegible] webers. Trial showed this to be the case, but the sound was a little lengthened. On repeating the experiment with 35 in circuit, none exploded; on removing a single fuze, 3 others detonated; on a third closing of the circuit, the rest went in a prolonged volley, showing that too much had still been demanded of the battery.

In like manner, six cells of the same battery were tried with type B; and equations (61), (62), and (63) showed that the best grouping would be nine series of 4 fuzes each, giving a current through each of the 36 fuzes of 0.67 webers. On trial, they all detonated instantly, with no lengthening of the sound. If the whole battery of nine cells had been used, the grouping would have been nine series of 7 fuzes each, giving 63 fuzes, through each of which 0.64 webers would have passed.

Upon comparing these results, it is evident that the new formulæ correctly indicated the best grouping.

It only remains to illustrate, by a practical example, the uses of the foregoing theory where a great number of mines are to be exploded; and, to give variety to the discussion, the power of a magneto-electric machine made by the Laflin & Rand Powder Company will be computed This machine, which is described in the next chapter, is a modified Wild, the permanent magnets being replaced by an electromagnet actuated by a small Siemens armature which supplies the current for creating the magnetic fields in which it and the working Siemens armature revolve. A very careful measurement of the constants of this machine was made; and, for a range covering the usual working speed, its equation was found to be the following, in which:

$C =$ the current in webers.
$T =$ the number of revolutions of the armature per minute.
$R =$ the external or working resistance in ohms.

$$C = \frac{0.02395\,T}{0.043 + R} \tag{67}$$

For the proposed computation, let T be assumed to be 1,500, giving for E 35.92 volts. $R_,$ is 0.043 ohms. Let it first be supposed that fuzes of type A are used; requiring for sure ignition, $C_,$ to be equal to 1.5 webers, and $F_,$ including the connecting wires, to be 1.0 ohms. Making use of ordinary leading wires for carrying the current from the machine to the groups, let them be assumed to be of copper No. 13,

B. W. G, each 500 feet long, giving for L, say 2.0 ohms. Then by equations (61) (62), (63), and (64):

$N = 70.2$, or say 72
$n = 11.97$, or say 12
$\frac{N}{n} = 5.86$, or say 6
$C_{,} = 1.48$ webers.

This result being far from satisfactory, let equation (61) be inspected to determine the cause; evidently, unless the machine or the rate of revolutions of the armature or the fuzes be changed, the quantity L offers the only field for improvement. Accordingly, let the 1,000 feet of leading wire of No. 13 B. W. G., be replaced by copper rods an inch in diameter, having a resistance of say 0.01 ohms. We then shall find:

$N = 2704$, or say 2,712
$n = 11.97$, or say 12
$\frac{N}{n} = 225.9$, or say 226
$C_{,} = 1.498$ webers.

Hence, by simply subtracting 1.99 ohms from the resistance of the main leading wires, the number of simultaneous explosions has been increased nearly 3,800 per cent., and yet a stronger current is sent through every fuze.

For the last arrangement, in which alone regard was paid to scientific principles, we find in equation (60):

$$R_{,} = 0.043$$

$$L + \frac{nF}{\frac{N}{n}} = 0.063$$

In other words, the well-known condition that, to develop the maximum power of any battery, the internal must equal the external resistance is approximately fulfilled. If L could conveniently be made zero, the accordance would be exact; and, provided F were not increased thereby, 3,348 of these fuzes could be exploded together.

To illustrate the importance of carefully selecting the fuze, the last computation will be repeated for type B (used at the great Hallett's Point blast) and for the two exceptionally sensitive types furnished by Digney and Breguet (page 238). Unfortunately the samples of these French fuzes were not large enough to permit a measurement of $C_{,}$; but the usual rule—three times the current requisite for a single fuze—is accurate enough for the present purpose. In estimating F for types A and B, the known resistance at explosion is increased by 0.18 ohms for the local leading wires; but for the French fuzes an additional allowance must be made on account of the

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increase in resistance caused by the excessive length of their bridges. Thus, for the Digney pattern this increase is 10 times and for the Breguet pattern 15 times that of the American types when passing from the cold state to that of ignition. For the first pattern 0.18 ohms and for the second pattern 0.36 ohms are allowed for extra increase—both probably less than the true value. The quantity L is taken at 0.01 ohms as before. The following table exhibits the results of the computation, which sufficiently illustrates the importance of careful study in preparing a fuze for difficult work.

Comparison of fuzes in large blasts.

Kind of fuze.	Resistance at explosion.	Current for 1 fuze.	Value of—		Computed values.			
			$C_{\prime}$	F	Total No. of fuzes. (N)	In each group. (n)	No. of groups. $\left(\frac{N}{n}\right)$	$C_{\prime}$
	Ohms.	*Webers.*	*Webers.*	*Ohms.*				*Webers.*
Type A	0.82	0.45	1.5	1.00	2704 say 2712	11.9 say 12	225.9 say 226	1.50
Type B	2.01	0.28	0.67	2.19	6190 say 6072	12.2 say 12	505.7 say 506	0.68
Digney	3.48	0.18	0.54	3.84	5434 say 5643	8.7 say 9	627.4 say 627	0.53
Breguet	5.69	0.13	0.39	6.23	6420 say 6083	7.4 say 7	868.8 say 869	0.41

In fine, then, this portable machine, requiring only about four horse-power, will supply an ample magneto-electric current to meet any demand likely to arise in submarine blasting upon the most extensive scale known upon modern works of internal improvement. From the principle of its construction internal resistance is nearly eliminated, rendering it possible, by proper grouping and the selection of a suitable fuze, to obtain the astonishing results indicated above.

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CHAPTER III.

IGNITING APPARATUS.

Frictional electricity.—The Austrian exploder.—Smith's frictional battery.—Mowbray's powder keg battery.—Bornhardt's frictional machine.—Voltaic induction.—The extra current coil.—Induction coils.—Magneto-electricity.—The Breguet machine.—The Jurgensen machine.—The Marcus machine.—The Wheatstone exploder.—The Beardslee machine.—The Gramme machine.—Dynamo-electricity.—The Siemens spark machine.—The Farmer machine.—The Smith machine.—The Laflin and Rand machine.—The Ladd machine.—The Siemens current machine.—The Hochhausen machine.—The modified Wild machine.—Voltaic batteries.—The nitric acid cell, two fluid.—The Benton iron cell, two fluid.—The chromic acid cell, two fluid.—The chromic acid cell, single fluid.—The dilute sulphuric acid cell, single fluid.—The sal-ammoniac cell, single fluid.—The peroxide of lead cell, single fluid.—The sesqui-oxide of iron cell, single fluid.—The sulphate of copper cell, two fluid.—The chloride of silver cell, single fluid.—The Clark standard cell, single fluid.—The secondary cell, single fluid.

Franklin, in his "Letters on Electricity" (June 29, 1751), was the first to suggest the employment of frictional electricity for the ignition of gunpowder.

In 1831, Moses Shaw, of New York, made the first actual application of this method to the explosion of mines.

The practical difficulties arising at that date from defective insulation of the apparatus, and especially of the leading wires, were so serious that attention was diverted to the heating of a fine platinum wire by a current of voltaic electricity, and that method soon superseded all others.

A sketch found among the papers of the late Col. Samuel Colt, of Hartford, widely known as the inventor of the revolving pistol bearing his name, is sufficient evidence that during his careful study of submarine mining he had become familiar with the practical advantages of the low-tension fuze. This sketch, which bears the date of 1836, indicates a method of firing the torpedoes at will, by the use of a fine platinum wire to be heated by a battery; and in his grand experiment upon the Potomac in 1843, he blew up a brig under full sail with a battery placed in Alexandria, five miles distant.

The first application of electrical ignitions in civil engineering was made by Sir Charles Pasley, of the Royal Engineers; who, in 1839, successfully used low-tension fuzes in the removal of the wreck of the Royal George at Spithead. He employed a form of the Daniell battery—which was invented by Becquerel in 1829, and reinvented by Daniell in 1836.

The earliest form of magneto-electric igniting apparatus suitable for field use was invented by Sir Charles Wheatstone about the year 1860. He was then working with Professor Abel to improve existing modes of exploding mines, and his machine was specially designed for use with the medium-tension fuze devised by the latter at about the same date. Since that time the subject has received constant study; and many modes of igniting explosive charges through the agency of electricity, in all its characteristic forms, are now available for the use of the engineer.

The duties of the Corps of Engineers include not only the defense of our harbors by submarine mines (for which the voltaic battery alone is suitable), but also that of rivers and inland channels where portable apparatus may sometimes be superior to any form of the voltaic cell; military mining, offensive and defensive on land; and civil works for river and harbor improvement, involving blasting on a large scale. Every known form of igniting apparatus is, therefore, of professional interest to our officers, and the investigations conducted at Willets Point, have covered a wide ground in this respect. In this chapter, therefore, the several modes of ignition will all be considered, and the most useful forms of generating apparatus will be described.

FRICTIONAL APPARATUS.

In principle these instruments are all identical. They consist, essentially, of a generator of frictional electricity; a condenser to receive, store, and multiply the charge; and a key to send it through the circuit and fuze at will.

The chief advantage of the class lies in the fact that when several fuzes are to be fired together the high potential of the electricity permits a straight or simple circuit to be employed. The explosions may therefore be considered as absolutely simultaneous, since the time of passage of the spark is too short to be estimated. With electricity of low potential and a derived circuit, on the other hand, ignition must occur in succession, the more sensitive fuzes exploding first. It is true that the intervals between these explosions are usually too short to be detected by the ear; but, with modern explosives, it can hardly be assumed that they have no influence upon the effect of the blast.

Wishing, in May, 1871, to study the laws which govern the action of a powerful spark sent into a circuit containing many tension fuzes coupled in series, I selected a priming verging on the safety limit (modified Dowse with 35 per cent. of plumbago), and connected 500 of the fuzes in straight circuit. They were inserted in small bottles charged with gunpowder and placed 14 inches apart. The whole formed a line on the beach about 600 feet long. All wire terminals were carefully insulated with roofing cement. Two main leading wires, each 900 feet long, extended from the terminal fuzes under water to a boat, and were attached to a Smith machine. These wires were insulated with gutta-percha; which, although quite new, was not of the best quality, especially in the later shots after a hot sun had softened it. The machine was giving 3-inch sparks; and charges of this quantity were sent, successively, into the circuit; but the long submerged wires reduced the effective spark to about half an inch. Fuzes which had exploded were not replaced, but the circuit was restored in each case.

The following table, which exhibits the details of this experiment, supports the conclusions:

I. That when a circuit is too long, the fuzes near the ends are the most likely to explode, the charge apparently being dissipated after doing its work upon them.

II. That it usually happens, when the charge is nearly dissipated, that it traverses the less sensitive fuzes and explodes those beyond them of a more delicate character.

III. That with one pole of the machine connected to earth and the other to one end of the fuze circuit, the other end being in air (trial No. 11), no material reduction occurs in the number of fuzes fired. This result suggested the following laboratory experiment: One pole of the machine was left insulated. The other was attached to a short leading wire which was terminated by one wire of a modified Dowse fuze, the free wire being in air. When the machine was discharged after being excited sufficiently to give about an inch spark under ordinary conditions, explosion usually occurred.

IV. That under the general conditions of this experiment, the normal number of simultaneous ignitions ranges from twenty to forty; average, nearly thirty. Experience in wet tunnel blasting fixes a similar limit to the power of Smith's machine with these fuzes, which verge on the extreme border of safety.

Many modified Dowse fuzes in series.

SMITH MACHINE.

No. of trial.	No. of fuzes in series.	South end.		North end.		Total fired.	Remarks.
		No. fired.	Last fuze fired (from end).	No. fired.	Last fuze fired (from end).		
1	500	13	No. 31	19	No. 37	32	
2	468	14	22	16	27	30	
3	438	23	42	2	5	25	Break in circuit not detected.
4	413	15	17	19	29	34	
5	379	2	2	14	28	16	Break in circuit not detected.
6	363	0	0	13	16	13	Break in circuit not detected.
7	350	0	0	24	38	24	Do.
8	326	9	18	14	27	23	
9	303	12	19	17	31	29	
10	274	11	14	11	22	22	
11	252	28	38	0	0	28	North leading wire disconnected, and battery put to earth.
12	224	10	25	13	35	23	
13	201	15	26	7	23	22	Shock received by operator.
14	179	23	25	15	29	38	
15	141	18	26	11	28	29	
16	112	10	12	3	3	13	Gutta-percha insulator of north leading wire softened by heat of sun.
17	99	17	18	4	4	21	Do.
18	78	10	10	3	5	13	Do.
19	65	18	23	2	3	20	Do.
20	45	18	19	8	12	26	Do.
21	19	(?)	(?)	(?)	(?)	19	Do.
Sum................		215	....	266	....	500	

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Another advantage of frictional apparatus is that it may be made lighter and more portable than any other kind having equal power.

On the other hand, this form of electricity has serious disadvantages, especially in its applications to submarine mining.

The potential necessarily being extremely high, accidental injuries to the leading wires are more serious than with most other apparatus, from the greater chances that they may cause miss-fires. It is, however, an error to consider that absolute insulation is essential, especially when a return wire is used. At the Torpedo School safe fuzes have often been exploded at ranges of 300 or 400 feet when both wires, submerged, exposed a little naked copper to the sea water; and fuzes of a kind considered to be over-sensitive, although perhaps not dangerously so, have been fired through submerged wires, each of which was naked for several inches.

The following experiments were made to test this matter in October, 1871, with fuzes primed with fulminate of copper mixed with 35 per cent. of plumbago, averaging about 0.9 microfarads for ignition, and hence near the limit of safety. The circuit consisted of two gutta-percha insulated wires, each 400 feet long, submerged in salt water. A Smith machine was placed in a boat and attached to these two wires in the usual way. The other ends of the wires were in the air, with the fuze connecting them. The machine was in rather bad order, requiring 45 turns for a 2-inch spark on short circuit. Through this submerged circuit the spark was reduced to half an inch. The insulation was removed from both wires at a distance of about 2 feet from the fuze, and the bared parts were submerged and kept 5 inches apart. The following experiments were then made, the fuze exploding in each case:

Each wire bared for 0.1 inch; fuze exploded with 1 turn; failing with 0 turn.
Each wire bared for 0.5 inches; fuze exploded with 3 turns; failing with 2 turns.
Each wire bared for 1.0 inch; fuze exploded with 3 turns; failing with 2 turns.
Each wire bared for 2.0 inches; fuze exploded with 25 turns; failing with 20 turns.
Each wire bared for 2.5 inches; fuze exploded with 35 turns; failing with 30 turns.
Each wire bared for 3.0 inches; fuze exploded with 35 turns; failing with 30 turns.
Each wire bared for 3.5 inches; fuze exploded with 40 turns; failing with 35 turns.
Each wire bared for 4.0 inches; fuze exploded with 40 turns; failing with 35 turns.
Each wire bared for 4.5 inches; fuze exploded with 40 turns; failing with 35 turns.
Each wire bared for 5.0 inches; fuze exploded with 40 turns; failing with 35 turns.
Each wire bared for 5.5 inches; fuze exploded with 45 turns; failing with 40 turns.
Each wire bared for 6.0 inches; fuze exploded with 45 turns; failing with 40 turns.

These experiments prove that perfect insulation is not essential with frictional electricity, even when the leading wires are submerged; and the fact that failures, with good fuzes, are rare in practice confirms this conclusion. For this class of igniting apparatus, two wires are much better than a single wire and the earth, since the tendency to leakage is reduced when the whole circuit is metallic.

Another difficulty, already discussed in the last chapter, must not be forgotten with frictional apparatus when several mines are to be fired separately, and the cables happen to lie near each other. The spark in passing through one cable is liable to induce so strong a disturbance in the electrical condition of the others as to ignite their fuzes. With submerged cables, this inductive effect is less than when they are on land; and long submerged cables are less exposed to it than short ones. For such cases experiment at the Torpedo School has developed a simple preventive, as has been already explained on page 222.

Another very serious difficulty attends the use of frictional apparatus in submarine mining. No pattern, as yet invented, will retain a full charge for any considerable time without loss; while to generate the requisite electricity requires perhaps half a minute. In this kind of service it is needful to be ready to fire instantly at the word; there is danger, therefore, either of sending too small a charge through the fuze, or of sending it too late, or of perforating the condenser by attempting to restore an over-estimated loss by an additional charge.

For these reasons frictional exploders are better suited to blasting than to defensive submarine mining. Four types will be considered.

The Austrian Exploder.—To Baron von Ebner, of the Austrian Engineers, is due the credit of first devising a machine of this character, suited for practical use in the ignition of mines.

The latest pattern of his instrument is encased in ebonite, and is protected by a teak box 16 by 7 by 17 inches, the whole weighing 32 pounds. It is capable of generating a spark about half an inch in length.

The generator consists of a double ebonite plate, 10 inches in diameter, revolving between four rubbers, each made of a brass plate covered first with flannel and then with leather. The leather is coated with an amalgam of zinc and tin, pulverized and applied with lard or wax; or with a thin coat of mosaic gold (stannic sulphide), rendered adherent by wax. These rubbers become charged with positive electricity when the plates are caused to revolve; the corresponding negative charge remaining on the latter, confined by silk flaps attached to the cushion next inside the leather. A brass rod with two sets of points, placed between the discs of the double plate, collects by induction this negative charge, as the discs pass in their near vicinity after leaving the flaps.

The condenser, placed in a box immediately under the generator, consists of a roll of alternate sheets of tinfoil and silk, having an inductive capacity of about 0.0003 microfarads. One set of tinfoil discs is in metallic connection with the brass collector, and the other set with the cushions. At every revolution of the plates the condenser thus receives a certain charge, which is rapidly augmented in accordance with the laws governing static induction.

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From the bottom of each end of the condenser box projects a brass terminal; these are connected together, and to one coating of the condenser, by a brass strap. One of these terminals is designed to receive a leading wire. At the other end of the box an insulated terminal, designed for the other leading wire, projects directly over the second and about 2 inches from it. By an ebonite key in the side of the box this third terminal may, at pleasure, be placed in metallic contact with the rod carrying the collecting points, and hence with the other side of the condenser, thus sending the charge of the latter through the fuze The second terminal (the lower on the end at which there are two) carries a movable brass rod to test the length of spark which the machine is capable of giving, and hence its condition and the requisite number of turns to perform the work required. Care must be taken to see that this pin is drawn down sufficiently to break this testing circuit before attempting to fire; and also to break the fuze circuit when using the testing circuit.

In dry weather, and when free from surrounding dampness, this apparatus is serviceable; but the protection against moisture is so imperfect that it is unfitted for use in wet places. It has been but little employed in this country, being far inferior both in power and insulation to the American exploder now to be described.

Smith's Frictional Battery.—This American modification of the Austrian exploder was patented in 1869, and is a great improvement upon the original. Indeed, it leaves little room for further progress in frictional blasting apparatus.

It has been very largely used in this country for railroad and other blasting. In the Hoosac Tunnel it was preferred to any other apparatus; and experience showed that it could be kept for weeks underground in the wet headings without injury from dampness. With good fuzes, not over-sensitive, it could be trusted to fire twenty holes simultaneously, in straight circuit, with only an occasional miss. It was cleaned and repaired at the works by workmen of ordinary intelligence. In fine, it proved itself to be a trustworthy instrument, portable and convenient. Extended experience at Willets Point has confirmed this good opinion of its merits. A single service tension fuze can be fired with it, through a submerged torpedo cable, at a distance of over 2 miles; and, for ranges of a few hundred feet, a slight loss of insulation in the leading wires does not cause a miss-fire With proper care, the only injury liable to occur is a perforation of the condenser, and this is not common; but in very warm weather the oiled silk flaps often adhere to the generator. To prevent this, the crank should frequently be turned a few times and the machine should be kept in a cool place; or, better still, the oiled silk should be replaced with some not oiled. It is well to use a return wire, thus avoiding an earth circuit which largely reduces the spark, beside aggravating the effect of small leaks in the leading wires.

The instrument is contained in a stout wooden box 14 by 14 by 7 inches, the total weight being 26 pounds. The essential parts are contained in a cylindrical ebonite box, 12 inches in diameter and 2 inches deep, from which dampness is excluded by a stout band of vulcanized rubber, 6 inches wide, overlapping the edges and clamped firmly by two iron plates, of which the lower one is permanently screwed to the bottom of the wooden box. The crank passes through a stuffing box in the top of the ebonite box, thus, in combination with the rubber band, entirely excluding damp air from the apparatus.

The generator consists of a disc of ebonite, 10 inches in diameter, which is revolved by a crank between two rubbers, consisting of straps faced with flannel and covered with oiled silk, the latter extending into flaps to confine the negative charge to the plate. The rubbers are coated with mosaic gold, and are pressed by back springs against the plate. The negative charge is collected, inductively, from the revolving plate by two brass serrated plates connecting with one coating of the condenser by a brass rod, the other coating being connected with the rubbers by a second brass rod distant 90° from the former.

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The condenser consists of four tinfoil discs, 8 inches in diameter and united two and two, giving a capacity of about 0.0022 microfarads, or seven times that of the Austrian exploder. These discs are embedded in ebonite, being inserted when the latter is in a soft state and vulcanized in position. All dampness is thus perfectly excluded. Projections from these discs extend to the circumference of the ebonite in four places, the two companion discs only appearing together. Four brass rods passing through these projections, supply two terminals to each set of plates. Two of these rods, as already stated, serve to connect the generating apparatus with the condenser. The other two are used to send the charge through the fuze when desired.

The arrangement of the firing key is exceedingly convenient. The condenser is firmly united by the four terminal rods, with others, to a top plate so placed as to allow room for the generating plate to revolve between the two. The whole essential apparatus thus remains pivoted and movable within the outer cylindrical box. Turning the crank to the right moves the inside work by friction, until it is stopped by an insulated pin; continuing the motion of the crank then charges the condenser. When a sufficient charge is accumulated, a backward motion of the crank moves by friction the inside work back 45°, when the second set of condenser terminals, mentioned above, are brought simultaneously in contact with two binding screws to which the leading wires are attached, thus sending the charge through the fuze.

Directions for using Smith's frictional battery are usually pasted inside the cover; but the following are the essential points: Never attach the leading wires to the terminals until everything is ready for the explosion. First move the crank to the right until the friction of the rubbers begins to be felt; attach the leading wires; revolve the crank to the right, slowly and steadily, the requisite number of times to give the proper length of spark for the number of fuzes in circuit; to fire, rapidly but gently reverse the motion until the rods strike the discharging terminals.

The number of turns which may safely be given to the crank varies from thirty to fifty, according to the condition of the machine. The number required to give a spark 2.5 inches long should not usually be exceeded. The following tests are extracted from the records at Willets Point. The first nine columns refer to a battery made by the Oriental Powder Company in 1870. It was freshly cleaned early in May, 1871; and, although constantly used in a row-boat, it remained unopened during the season. The last column exhibits tests of a battery supplied by Mr. George E. Lincoln in 1872, the best of these instruments which I have ever seen. The sparks were all measured between points on a universal discharger.

Tests of Smith's frictional battery.

Length of spark in inches.	Number of turns of crank required.									
	April 19, 1871.	May 23, 1871.	May 25, 1871.	May 29, 1871.	June 9, 1871.	July 13, 1871.	July 26, 1871.	Sept. 20, 1871.	Jan. 26, 1872.	April 12, 1872.
0.5	....	8	8	9	11	13	14	14	13	5
1.0	13	11	11	13	15	17	20	18	28	8
1.5	17	14	14	16	19	19	23	24	43	13
2.0	21	18	17	19	20	25	27	35	73	15
2.5	25	20	19	22	23	....	32	48	....	20
3.0	34	24	22	25	....	....	....	....	....	25
3.5	....	....	....	....	....	....	....	....	....	28
4.0	....	....	....	....	....	....	....	....	....	34

To clean and re-coat the rubbers, open the apparatus in a dry room. Scrape off the old wax. Wash off with alcohol any mosaic gold which may adhere to the plate, and dry thoroughly. Warm a spatula, touch it to clean beeswax, and apply a thin coat to the rubbers. Sift over it some finely powdered mosaic gold. Apply a flat-iron hot enough to soften but not melt the wax. Rub the rubbers together until they look like bright mosaic gold, and then shake off all loose powder. Thoroughly warm and dry all the inside work, and put the instrument together. Be careful never to touch the rubbers or plate with the fingers.

Another method of re-coating the rubbers is the following: Thoroughly warm the cushions and mosaic gold; heat the spatula sufficiently to melt the beeswax, and thus apply a thin fluid coat; dust the mosaic gold rapidly over it until no more can be absorbed; lastly, apply a cold flat-iron, and, after a smooth surface is obtained, shake off any loose dust.

Mowbray's Powder Keg Battery.—This instrument was patented in 1874. Mr. Mowbray's ideas were to reduce the danger of perforating the condenser, by increasing the inductive capacity; and to employ a cylindrical instead of a flat generating disc, in order to secure a larger supply of electricity from a given number of turns. To gain these advantages he was willing to sacrifice, in some degree, the remarkable insulation attained by Smith.

The instrument is contained in a strong chest 19 by 14 by 13 inches, the whole weighing 42 pounds. For use, the apparatus is removed from the chest, presenting the appearance of a powder keg handsomely varnished, and weighing 18 pounds. At one end the crank is inserted; and at the other, the leading wires are loosely thrust about an inch into holes in a couple of firing plugs. Temporarily fitted into these holes are two wires connecting with a convenient sliding apparatus for testing the length of spark. The capacity of the condenser is 0.0036 microfarads, or 1.65 times that of Smith's. The length of spark with sixty turns of the machine, in good order, is about 1 inch, corresponding in quantity to one of about 1.7 inches from Smith's battery. Mowbray's apparatus is, therefore, decidedly inferior in power; but, the potential being lower, an equal charge is somewhat less likely to escape through leaks in the leading wires.

The generator consists of an ebonite cylinder, 11 inches long and 6.25 inches in diameter, revolving in contact with a rubber formed of soft elastic felt, 8 inches long and 5 inches wide, backed with hair. This rubber is two-thirds covered with oiled silk coated with mosaic gold, the remaining third being left with a clean felt surface to brush any adherent mosaic gold from the cylinder as it revolves past it. The oiled silk extends into a flap, as usual, to prevent the dissipation of the charge from the cylinder. The collector is a movable rod studded with points, serving also as a stop to limit the revolution of the open case containing the generator; which, as in Smith's machine, is moved forward about 60°, to prepare to charge the condenser, and backward a like amount to send the spark through the fuze, thus dispensing with a separate firing key.

The condenser consists of two thin plates of ebonite, with tin-foil attached to their opposite sides. They are placed loosely around the case enclosing the generator, between it and the wooden keg, being held in position by a band of thin rubber. In order to take up moisture, a padding of flannel, containing a mixture of quicklime and mica scales, is placed between the condenser and the middle part of the keg.

In fine, the instrument is more unwieldy, less powerful, less perfectly protected against dampness, and far more difficult to open and clean than Smith's. The arrangements for attaching the leading wires are defective; both because the latter are liable to work out when charging the condenser, and because, as experience has shown, they may break off in the firing plugs, leaving an end which obstructs the hole and is difficult to remove. On the other hand, the condenser is less liable to perforation; the spark has a less tendency to escape from the leading wires; the mosaic gold and flaps do not so readily adhere to the generator; and, lastly, the testing of the instrument is more convenient.

Bornhardt's Frictional Machine.—This machine is largely employed in France for electrical blasting, being favored by the Société Générale pour la Fabrication de la Dynamite for use with their explosives. Two sizes are made, of which the larger may be described as follows:

The machine is contained in a wooden case, 21 inches long by 11 inches wide by 16 inches high, the whole weighing 42 pounds. One end has a hinged cover, which, when opened, exposes a shallow compartment containing the terminals, the firing key, and the testing scale. The latter consists of 16 copper-headed tacks, driven on a straight line 7 inches long, leaving 15 small intervals aggregating about 1.4 inches in length. Chains are provided for connecting the end tacks with the terminals. The number of turns required to generate a spark that will traverse the tack heads is the gauge of the condition of the instrument. From twelve to sixteen turns are stated by the inventor to be the usual number, but even twenty-five are admissible.

The top of the box is secured by ten screw bolts. When removed it exhibits an iron case filling the entire cavity, and closed by a flat ebonite cover which is held closely in contact by six steel springs compressing an elastic cushion.

The generator consists of two circular ebonite discs, 3 inches apart, each 11½ inches in diameter and rigidly attached to the common axis. Revolution is given by a crank on the outside of the box, one turn of the crank being multiplied by gearing to give three and a quarter turns of the discs.

The rubbers each consist of a strip of cat skin, 4 by 2½ inches in size, wrapped over the edge of the disc and pressed against it by two steel springs with large washers. These springs are in contact with the metal of the inner box, and thus place both of the rubbers in metallic connection with the outer coating of the condenser and with the lower external terminal.

The collectors for each disc consist of two tin-foil rings armed with the usual points and held near the edges by a wooden frame. This frame rises from two pint bottles to the corks of which it is attached. These bottles are coated with tin-foil, and together they constitute the condenser of the machine, having a capacity of 0.0010 microfarads. The inner coating is connected with the collectors by spiral springs and a tin-foil circuit carried inside the wooden frame to secure insulation. The outer coating is placed in electrical contact with the iron case by metallic clasps, which hold the bottles in position.

The discharging key is a brass rod with an outer ebonite head. When pressed it moves an ebonite rod 8 inches long, so as to close the circuit between the inner coating of the jars and the upper external terminal. This is effected by an insulated brass ball carried on the end of the rod and connected with the terminal by a spiral brass spring. To prevent escape, this terminal is protected by two circular ebonite plates, 6 inches in diameter, one inside and one outside the metallic case. They are connected by an ebonite tube through which the metallic circuit is carried.

To absorb moisture, two wooden boxes, each 12 by 3½ by 1½ inches, packed with charcoal and covered by paper, are inserted near the rubbers.

To use the machine, the testing scale is connected with the terminals by its chains, and the number of turns required to cause the spark to jump along the tack heads is found by trial. The chains are then replaced by the leading wires, and a similar charge is sent through the external circuit.

The following test was made between points on a universal discharger, when the instrument was first received from France in February, 1881.

To give a spark ½ inch long required 1½ turns of crank.
To give a spark 1 inch long required 4 turns of crank.
To give a spark 1½ inches long required 7 turns of crank.
To give a spark 2 inches long required 9 turns of crank.
To give a spark 2½ inches long required 14 turns of crank.

The scale test required only three turns of the crank, showing that the instrument was in unusually good order.

The marked merits of this machine are: The crank gearing, by which the time and labor of changing the jar are reduced about two-thirds; the cat-skin rubbers, which seem to be effective, and little liable to deterioration; and the great facility afforded for cleaning and drying the working parts. The demerits, as compared with the Smith battery, are the bulk and weight of the box; the inferior condensers, which have only half of the capacity and are more exposed to mechanical injuries; the less convenient arrangements for firing; and the less perfect precautions for excluding damp air from the interior. With poorly insulated leading wires, and especially for use in damp headings, the American machine is the better of the two.

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VOLTAIC INDUCTION APPARATUS.

This class of igniting apparatus is based upon what are known as the laws governing the inductive action of electrical currents upon neighboring conductors. These laws may be briefly stated as follows:

A current beginning, increasing, or approaching induces in a neighboring conductor parallel to it an instantaneous current, or rather, wave, moving in a direction the reverse of its own; and ceasing, diminishing, or receding, it in like manner induces an instantaneous wave moving in its own direction. These effects are produced whether the primary current be continuous, like that of a voltaic battery, or instantaneous, like a frictional spark.

The stronger and the more sudden the changes in the primitive current the greater is the strength of the induced wave. An unchanging current fixed in position in respect to a neighboring conductor does not disturb its electrical equilibrium.

If the primary conductor be thrown into a coil and the secondary conductor envelop it, these effects are intensified; and they may be still further increased by enclosing a soft iron core within the helices.

The properties of the induced current may be varied by varying the length and kind of wire constituting the secondary circuit. Thus, if this be short and stout, low potential and large volume will result; if long and fine, high potential and small volume will be obtained. The latter effects may be made to resemble the former by attaching the opposed plates of a suitable condenser to the terminals of the secondary wire where the sparks appear.

If the primary coil be used without an enveloping secondary, the mutual action of the convolutions upon each other will induce a similar phenomenon, which has received the name of the *extra current*. This current is inverse in direction to the primary when the battery circuit is closed, and direct when it is opened. In the first case it reduces, and in the second case it augments, the strength of current flowing in the conductor. With a strong battery and a compact helix containing many convolutions, the extra current becomes a powerful wave, capable of producing astonishing effects of quantity; but its potential is always low as compared with that of the current which would be induced in an ordinary secondary circuit.

Although various forms of igniting apparatus, based upon the principles of voltaic induction, and usually reinforced by magnetic cores, have been proposed—the first by Colonel Verdu, in 1853—none of them have yet been made so portable and well insulated as to be suited for the field. For a torpedo casemate, however, the conditions are not so difficult to fulfil; and, as the class possesses certain incontestable merits, it has been experimentally studied with some care at Willets Point.

Difficulties have arisen from the well-known absorption and temporary retention of large charges by submerged cables, and from troublesome currents induced in neighboring cores, which sometimes endanger their mines; but a fair measure of success has been reached, which renders it possible, if desired, to ignite at will mines operated upon an open circuit. Three distinct kinds of apparatus have been constructed, and they will be described in turn.

The Extra Current Coil.—Baron von Ebner made use of this principle for firing the mines of his system, as exhibited at the Paris Exposition in 1867; but the details of his apparatus have not been fully made known.

The instrument devised in 1872 for trial at Willets Point consisted of one statute mile of copper wire, No. 12½ B. W. G., insulated with cotton and coiled around a bundle of iron wires. Its resistance was 8 ohms. By a mercury key the firing battery, composed of 100 large cells of a zinc coke variety of the Smee battery, was caused to send a current through this coil at will. A shunt circuit passing from one pole of the battery through the cable and fuze and returning through the earth to the other pole was arranged. The fuze prepared for this use belonged to the high tension class, and offered so great a resistance that the direct current even of this large battery failed to traverse it sufficiently to cause explosion; but when the coil circuit was closed and suddenly broken by the key, a great wave of electricity was shunted into the cable, having sufficient electro-motive force to break down this resistance and fire the mine.

This apparatus developed immense quantity. The shock sent from one side of a finger to the other, produced a numbness of the whole hand which lasted many minutes; and if sent through the body its effects would probably have been serious.

With suitable fuzes which could not be exploded by a direct current, the apparatus could be trusted to fire a torpedo through a submerged cable at a distance of 2 miles; and the quantity of the wave was so great that from twenty to thirty fuzes attached in derived circuit could be exploded simultaneously, or nearly so, at the same distance.

These results were regarded as satisfactory; but when the progress of the investigations had shown that a small break between the cable and the high-tension fuze was needful to guard against accidental explosions due to currents induced in neighboring cores by the firing of one mine, the apparatus had to be given up. This little break could not be passed by the extra current wave, and no means of increasing the potential sufficiently to overcome the difficulty was discovered

Special Induction Coil.—Since the tendency to aggravate small faults in the cable increases very rapidly with the potential of the electrical charge, it is important in submarine mining to limit this element to the lowest possible point consistent with certainty of action. Efforts were accordingly directed to preparing a special apparatus in which the secondary wire should be shorter and of coarser gauge than is usual, thus producing a spark of large quantity and of low potential.

The instrument, completed in December, 1873, was constructed like an ordinary induction coil with a mechanical break circuit arrangement. The primary coil consisted of 0.16 ohms of insulated copper wire, No. 10 B. W. G., wrapped around a soft iron core. The secondary coil contained 82 ohms of insulated copper wire, No. 23 B. W. G.

With nine Bunsen cells, coupled in three series of three cells each, this apparatus gave a spark about one-fourth of an inch long and characterized by great quantity; but experiment indicated that even with this inconveniently large battery it lacked power to be certainly effective through a submerged cable at a range of one mile, when the fuze was protected by a break. Attention was accordingly directed to a different method.

Service Induction Coil.—After a series of tests, terminating in 1874, a small induction coil 14 by 6 by 7 inches high, and weighing 18 pounds, was adopted. The primary wire is of No. 14 B. W. G., having a resistance of about 0.1 ohm. The secondary is of No. 35 B. W. G., with a resistance of about 2,800 ohms. The break is of a simple automatic kind, and a current of about 4.5 webers is required to give a continuous stream of sparks an inch and a quarter in length. Two large Grenet cells coupled in series are well suited for supplying this current. Between the terminals of the secondary wire is connected a small 6-inch condenser, made like those of Smith's frictional machine, having a capacity of 0.0006 microfarads. Its effect is greatly to increase the density of the sparks at the expense of their length, which now becomes about half an inch, but it does not sensibly lessen their rapid sequence. One of the secondary current terminals is put to earth, and the other to the cable leading to the mine. On closing the primary circuit, a torrent of powerful sparks passes into the cable to ignite the tension fuze placed in the mine for the purpose. With a well insulated conductor, the machine is effective at a range, under water, somewhat exceeding a mile.

This apparatus proved to be serviceable and convenient for mines operated upon an open circuit. The conductor in the fuze can is provided with two circuits to earth—one through a low-tension fuze and the circuit closer, for automatic firing when the torpedo is struck by an enemy, and the other through a $\frac{1}{100}$-inch break and a medium-tension fuze for judgment firing. For the latter purpose a convenient double switch key is provided, which in one position closes the primary circuit, and in another applies the ordinary firing battery to the cable—thus igniting the mine at will whether the circuit at the torpedo be opened or closed.

MAGNETO-ELECTRIC APPARATUS.

Magneto-electricity, *i. e.*, electricity generated by magnetism, has of late years received much attention; and so great improvements have been introduced in the apparatus that, for certain classes of practical applications, it bids fair to supersede the voltaic cell. Through its agency mechanical energy may be transformed into electricity of almost any desired potential and quantity.

The fundamental principle upon which this mode of generating electricity depends, is identical with the voltaic induction just described. Indeed, according to the accepted theory, the phenomenon of magnetism is due to a series of electrical currents, circulating around the molecules in a common direction; and the resultant of the effects of such a system is equivalent to that of a single current circulating round the exterior of the magnet. Facing the north seeking pole, the direction of this resultant current is contrary to that of the hands of a watch; facing the south seeking pole, it accords with their direction.

Adopting this theory, let the north seeking pole of a magnet be inserted by successive movements into a continuous ring of wire. According to the laws of voltaic induction, above stated, an instantaneous current of electricity will be induced in the ring at every motion, their direction when looked at from the side on which the magnet is inserted being the reverse of that of the hands of a watch. Withdrawing the magnet in the same manner, instantaneous currents will be excited in the same direction as that of the hands of a watch.

If the south seeking pole be approached to or withdrawn from the ring, similar currents, but reversed in direction, will be induced.

If now the single ring be replaced by a spiral coil and the magnet be moved as before, the currents induced will be characterized by higher potential, their direction being the same as before.

If, instead of moving the magnet, a piece of soft (unmagnetized) iron be permanently inserted in the spiral, and by rapid contacts with the pole of a magnet be successively magnetized and demagnetized, instantaneous electrical currents will circulate as before.

If the poles of a permanent magnet be extended by soft iron rods surrounded by helices of wire, and the armature be applied or withdrawn suddenly, currents in these helices will be developed by the resulting change in the locus of maximum magnetic intensity.

Upon these fundamental principles are based all the varieties of magneto-electric apparatus, their differences consisting simply in different mechanical devices for effecting magnetic changes within or near a coil of insulated wire.

If currents of high potential are desired, the coils are made of fine wire; while if large quantity is needed, coarse wire is used. In either case it must not be forgotten that the *duration* of the current is very short; and that, if a continuous succession of waves approximating to a continuous current be desired, a very rapid succession of contacts and breaks must be provided. The current will then consist of a succession of waves in opposite directions—which, however, by the aid of what is called a commutator may, if desired, be caused to coincide in direction. Thus modified, magneto-electric currents become very similar in their effects to those obtained from a voltaic battery.

The electricity generated by magneto-electric machines has a lower potential than that given by frictional and voltaic induction apparatus; indeed, it more nearly resembles, both in potential and in quantity, the voltaic current from many cells coupled in series. It is therefore less liable to escape through defects of insulation in the leading wires than that obtained from the machines already described; but, on the other hand, it exacts more attention to guard against small breaks in the continuity of the circuit.

Magneto-electric machines may be classified according to the form in which the force is utilized. Thus, in the progress of invention, instruments were made which acted (1) by a single wave; (2) by a succession of waves alternating in direction; (3) by a current more or less unvarying. It may be added, that by the device called a commutator, an alternating current may always be transformed into one pulsating in a single direction, thus transferring the instrument from class (2) to class (3).

The following tabular classification, based on the foregoing analysis, exhibits the magneto-electric igniting machines in most common use:

I. Acting by single electric wave.	Breguet. Jürgensen. Marcus.
II. Acting by a succession of waves alternating in direction.	Wheatstone. Beardslee.
III. Acting by a continuous current.	Class II, with commutators added. Gramme.

It may be remarked, in general terms, that Classes I and II require medium tension and Class III low tension fuzes; but each kind of instrument, as a rule, has peculiarities which render it important to select its fuze with judgment. High-tension fuzes can hardly be used with any variety.

In order to convey a fair idea of the relative power and convenience of these several machines for different classes of practical work, the following description of them is added. It will enable the officer to select the one best suited to his needs in any special case. The dimensions refer to sample instruments belonging to the School of Submarine Mining at Willets Point, and are the results of careful measurements. The plates are designed to explain the electrical principles, not the mechanical details of the apparatus.

The Breguet Machine.—This instrument (Plate XXIII, Fig. 1) consists of a horseshoe-magnet, the poles of which, prolonged with soft iron, constitute the cores of two induction coils of very fine insulated wire, having a resistance of 9,400 ohms. A soft iron armature in contact with the ends of these cores is attached by a brass plate to a lever extending outside the case. This lever is so pivoted on a horizontal axis that a smart blow will separate the armature suddenly from the poles, and thus cause a current, induced by the change in the locus of magnetic polarity, to circulate through the coils. This current is greatly intensified by an extra spark caused by the following ingenious device: The coils are united in series, and the circuit is extended to two terminal posts outside the case. Another circuit, forming a shunt between the coils and the terminal posts, consists in part of a spring attached to the lever and moving with it. After moving a certain distance, this spring breaks the shunt circuit, thus producing a strong extra spark by the interruption of the current at its maximum. It is chiefly this spark which passes through the exterior circuit and fires the fuzes.

The instrument is encased in a neat box 18 by 7 by 6 inches high, the whole weighing 21 pounds. A sliding key blocks the lever when not in use, and thus guards against accidents from careless handling. A switch and five posts on the cover allow any one of five torpedoes to be fired at will.

A tension fuze possessing a decided conductivity, like those of Abel or von Ebner, is required with this machine; and to effect simultaneous explosions it is well to select fuzes nearly alike in this respect. This may be done by noting the deflections of a delicate galvanometer included with the fuze in the circuit of a small battery. Of course, fuzes must be coupled in series with this class of machines, but where more than one fuze is used some other class should be selected.

Sweden at one time adopted the Breguet apparatus for naval uses, but ultimately decided it to be deficient in quantity—especially for submerged cables, in which electrification largely reduces the volume of the spark. It is stated that on a land line, in 1869, a fuze was fired at a distance of 300 miles by this machine.

It is not easy to establish a standard by which to compare different kinds of igniting apparatus acting by a single wave, for the reason that the instruments differ both in the quantity and the potential of the charge; and the latter element passes from zero through an unknown maximum back to zero in a time immeasurably short. If, however, fuzes having a suitable conductivity are to be employed, an approximate idea of the relative power of two machines may be derived from a galvanometer measurement based upon the following principles:

If the currents to be compared be instantaneous, and the needle be so heavy as not to move sensibly during the passage of the waves through the coils, the observed swings of the needle may be regarded as the effect of blows.

In this case the mechanical work is proportional to the versine of the angle of swing (a), *i. e.*, to $2 \sin^2 \frac{a}{2}$. The electrical work is measured by the product $C^2 R T$; in which C denotes the strength of current, R the resistance of the circuit, and T the time. Hence, for two currents through the same circuit:

$$(68) \qquad C_{,} = C_{,,} \frac{\sin \frac{a_{,}}{2} \sqrt{T_{,,}}}{\sin \frac{a_{,,}}{2} \sqrt{T_{,}}}$$

Now if a known wave ($C_{,,}$), of such a nature that the ratio between the square roots of the two times may be assumed to be unity, be sent through a galvanometer, and its swing ($a_{,,}$) be noted, and a like observation be made with the machine to be tested (giving $a_{,}$), this formula will furnish an approximate measure of the power of the latter in known electrical units.

This method has been applied to the Breguet apparatus, using for the standard a known condenser charged by a battery of known potential. The latter was 328 volts. Two condensers were employed, the first having a capacity of 1.510 microfarads

FIG 1. BREQUET MACHINE

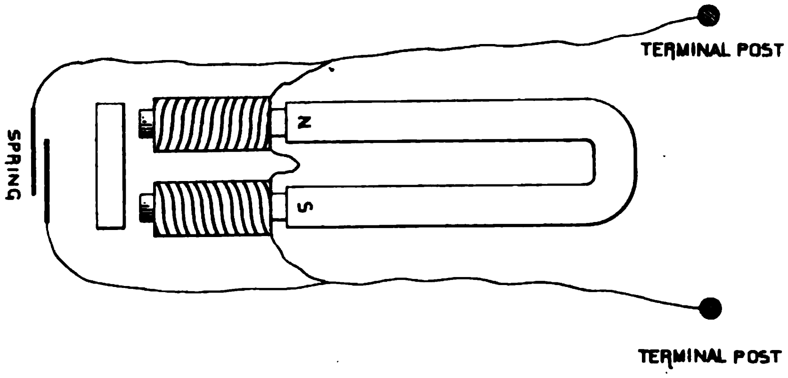


FIG 2. MARCUS MACHINE.

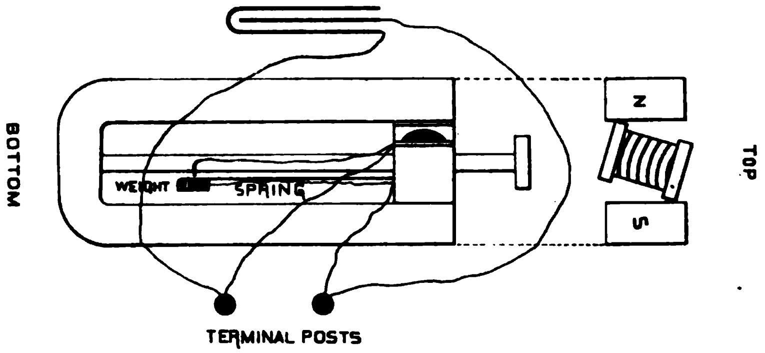
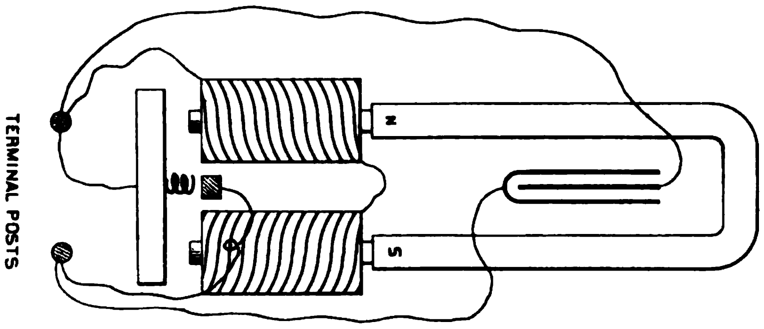


FIG. 3 JÜRGENSEN MACHINE



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and the second 2.344 microfarads. The galvanometer was a fine instrument made by Siemens Bros., of London, and well suited to this use. The mean results of several measurements, differing but slightly among themselves, were the following:

The first charge (492 microfarads) deflected the needle 6.0 degrees.
The second charge (768 microfarads) deflected the needle 9.4 degrees.
The Breguet apparatus deflected the needle 17.1 degrees.

Hence, by equation (68) the charge given by the Breguet machine was:

$$\text{By first standard: } C_{,} = 492 \times \frac{0.1495}{0.0523} = 1{,}407 \text{ microfarads.}$$

$$\text{By second standard: } C_{,} = 768 \times \frac{0.1495}{0.0816} = 1{,}402 \text{ microfarads.}$$

This method is not rigidly exact, even in theory, but it is the best which has suggested itself to me; and this remarkable coincidence in two independent measurements, indicates that these figures may be not without practical utility in comparing apparatus of this class.

The Jürgensen Machine.—This apparatus (Plate XXIII, Fig. 3) is identical with the Marcus machine (soon to be described) in electrical principles, although differing widely in mechanical details. It was adopted in the Danish naval service for boat use, being compact and portable, but it is rather deficient in power.

The case is of wood, 12 by 6 by 4 inches in size, and the whole weight is 16 pounds. It contains a horizontal permanent magnet, of which the poles, prolonged by soft iron, form the cores of two coils of fine copper wire having a total resistance of 1,170 ohms. The two free ends of these coils are attached to terminal posts outside the case, which are also connected with the opposite coatings of a small condenser having a capacity of 0.0024 microfarads. A shunt circuit also connects the terminals, consisting in part of a spring moving with the armature, which, when the current induced by the magnetic wave traversing the cores of the coils is at its maximum, breaks the shunt, and discharges the extra spark thus induced, multiplied by the condenser, through the fuze.

The mechanical device for removing the armature is the following: In its normal condition this armature is separated from the core ends, being attached to a horizontal rod extending between the bars of the magnet. A strong spiral spring holds the armature away from the poles. A keeper to preserve the strength of the magnet, is in contact with the under part of the poles beyond the coils. To set the apparatus for firing, the end of this horizontal rod, which projects beyond the case, is pressed in until the armature touches the cores, when the rod is caught and held by a latch-spring. This motion also removes the keeper by a neat device. On touching the trigger, the latch-spring is released and the coiled spring jerks off the armature, thus inducing a magnetic wave through the cores which generates the desired current in the coils.

Like the rest of its class, this instrument requires medium-tension fuzes; and they should be coupled in series if more than one be used.

To determine the strength of current which the Jürgensen machine is capable of developing, measurements were made by the method described for the Breguet machine. While the two condensers charged to a potential of 328 volts gave swings of 6 and 9.4 degrees, respectively, this instrument gave 36 degrees. Hence, by equation (68):

$$C_{,}=492\times\frac{0.3090}{0.0528}=2{,}906 \text{ microfarads.}$$

$$C_{,}=768\times\frac{0.3090}{0.0819}=2{,}897 \text{ microfarads.}$$

Hence, the instantaneous current from this apparatus is stronger than that of the Breguet machine in the ratio $\frac{2902}{1404}=2.1$ times. This result is confirmed by four direct comparisons made in 1875 and 1880, upon the same galvanometer, with its swing regulated by a magnet placed near the needle. Thus:

Breguet, 4.0 degrees; Jürgensen, 9.5 degrees; ratio by equation (68), 2.3 times.
Breguet, 6.2 degrees; Jürgensen, 14.5 degrees; ratio by equation (68), 2.2 times.
Breguet, 8.2 degrees; Jürgensen, 18.4 degrees; ratio by equation (68), 2.0 times.
Breguet, 16.3 degrees; Jürgensen, 35.3 degrees; ratio by equation (68), 2.1 times.

Mean ratio, 2.15 times.

The Marcus Machine.—This instrument, suggested by Baron von Ebner, of the Austrian Engineers, in 1862, is very compact and ingenious, and is said to be adopted in the land service of Austria and Prussia, and in the French naval torpedo service. It is 5 by 4 by 13 inches in size, and weighs 20 pounds. (Plate XXIII, Fig. 2.)

A large horseshoe-magnet constitutes two sides and the bottom of the case. The other two sides are of ebonite; and the top is of brass, carrying a discharging key and handle for setting. The latter forms the top of a vertical shaft extending between the bars of the magnet from top to bottom. Between the poles, it carries an armature of soft iron in shape like a square-headed spool. This spool is wound with 280 ohms of insulated copper wire, No. 26 B. W. G., of which the ends are attached to two terminal posts on one of the ebonite sides of the box. These posts are also connected to the opposite plates of a condenser having a capacity of 0.017 microfarads. Between the terminals is also placed a shunt circuit, consisting in part of a long spring held in place by a weight at its lower end.

In its normal condition the ends of the spool stand diagonally between the poles of the magnet, the edges in contact with them. To set the instrument for firing, the shaft carrying the armature is turned horizontally through a sufficient angle to bring the opposite edges of the heads of the spool in contact with the magnet, thus develop-

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ing the force of a strong steel mainspring. On touching the trigger this spring violently turns the shaft and armature back to its normal position, thus reversing the polarity of the core of the coil and generating a current of electricity in the latter. The inertia of the weight on the spring, developed by the shock, breaks the shunt circuit and sends the extra current thus induced, reinforced and multiplied by the condenser, through the exterior circuit to fire the fuze.

This instrument requires a conducting tension fuze, like the Abel or von Ebner; and if more than one be used they must be united in series. It is rather deficient in power, especially where the circuit consists of a submerged cable: but from the size of its condenser and its reversal of the polarity it gives a smart shock.

An attempt failed to directly compare, by equation (68), the strength of current developed by this machine with the discharge from the two condensers, because any measurable swing from the latter corresponded to one off the scale from the former The only method, therefore, was to use the damping magnet and adopt the Jürgensen machine as a standard, which accomplished the desired result, since the strength of current of that instrument in microfarads had been accurately determined. The following figures give the results of this comparrison, which was made in 1875 and repeated in 1880:

Jürgencen, 9.5 degrees; Marcus, 29.2 degrees; ratio by equation (68), 3.0 times.
Jürgensen, 14.5 degrees; Marcus, 50.2 degrees; ratio by equation (68), 3.3 times.
Jürgensen, 18.4 degrees; Marcus, 60.0 degrees; ratio by equation (68), 3.1 times.

Mean ratio, 3.13 times.

Hence, the discharge of the Marcus machine is: 2902×3.13=9,083 microfarads, or about six and a half times more than that of the Breguet machine.

The Wheatstone Exploder.—This instrument, which appeared about the year 1860, was the earliest magneto-electric machine destined to be extensively introduced in practical blasting. It was a successful modification of apparatus similar to that already described, and was designed to replace the single wave by a very rapid succession of currents alternating in direction. These currents, thrown at will into the exterior circuit containing the fuzes, increased the certainty and the possible number of explosions.

The perfected machine (Plate XXIV, Fig. 1) consists of six seven-plate permanent horseshoe-magnets, so disposed around a central brass axis, in a stout case, as to bring all the poles upon the circumference of a vertical circle. To each pole are attached two soft iron rods, each wound with fine insulated wire, No. 23 B. W. G. The twenty-four coils are all united in series, and the ends are attached to exterior. terminal plates. The joint resistance of the interior circuit is 8,400 ohms, or 350 ohms to each coil.

One of the terminal plates is to be put to earth; the other carries six movable firing pins. When a pin is depressed it closes the circuit between the plate and one of six insulated binding posts designed to receive the leading wires from a set of six mines. The full speed of revolution can thus be gained before closing the circuit; and the desired charge, or group of charges, can be exploded without endangering any of its five neighbors and without shifting leading wires.

The variation in the magnetic strength of the soft iron cores, upon which the generation of the current depends, is effected by revolving six soft iron armatures rigidly attached to separate shafts geared to a common central axis which is moved by a crank. One revolution of the latter causes six revolutions of each armature, and a high speed is thus secured.

The armatures revolve in close proximity to the exposed ends of the rods forming the cores of the coils. The four coils belonging to each magnet are disposed at the angles of a square, with the shaft of the armature in the middle. The width of the armature is such that at the instant when it leaves one core it reaches the next. The winding is so arranged that the current induced by leaving one set of diagonal cores is in the same direction as that induced by approaching the other diagonal set. The whole circuit is thus traversed by two negative and two positive equal currents during each revolution of the armature. As the six magnets are similarly wound, they unite to strengthen these currents, of which there are, of course, twenty-four at each revolution of the crank. Great uniformity and rapidity is thus secured.

It is found, practically, in instruments of this class, that better results are obtained by periodically short circuiting the cores. Wheatstone effects this by attaching one terminal wire to the metallic axis of the instrument, and the other to an insulated spring. The latter presses on an ebonite cover fixed upon one of the armatures. Once in each revolution of the latter, the spring touches a platinum pin connected with the armature, and thus with the axis of the instrument.

The case is 12 by 11 by 12 inches, and has a total weight of 58 pounds. The crank handle is much too short for convenience.

The available potential is not sufficiently high to allow many fuzes to be coupled in series, and a simple derived circuit should therefore be employed. Only tension fuzes possessed of considerable conductivity can be exploded by the machine.

A series of careful experiments conducted by the British Government, and fully reported in Vol. X, New Series, Professional Papers of the Royal Engineers (1861), exhibit the following results: Employing the Abel fuze and a derived circuit, from twelve to twenty-five charges at 600 yards from the machine can be exploded on land, and four under water. A single fuze has been exploded through over 100 miles of land telegraph wire. Insulation must be carefully secured; and the explosions in derived circuits are not absolutely although very nearly simultaneous.

FIG. I. WHEATSTONE EXPLODER.

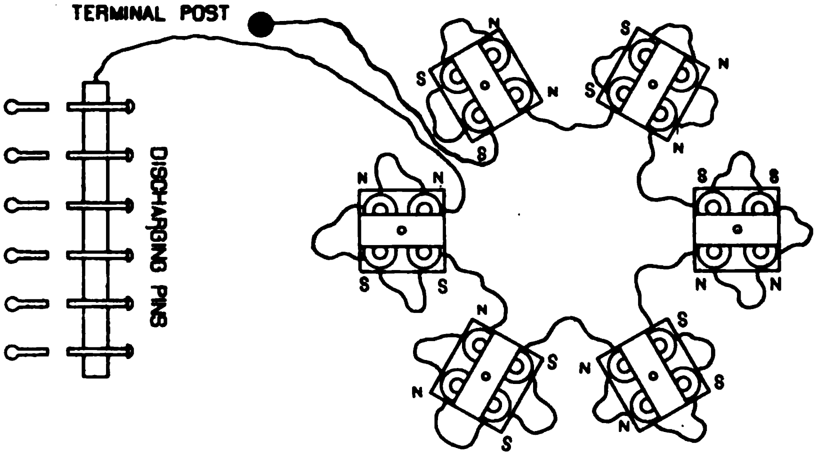


FIG. 2 BEARDSLEE MACHINE.

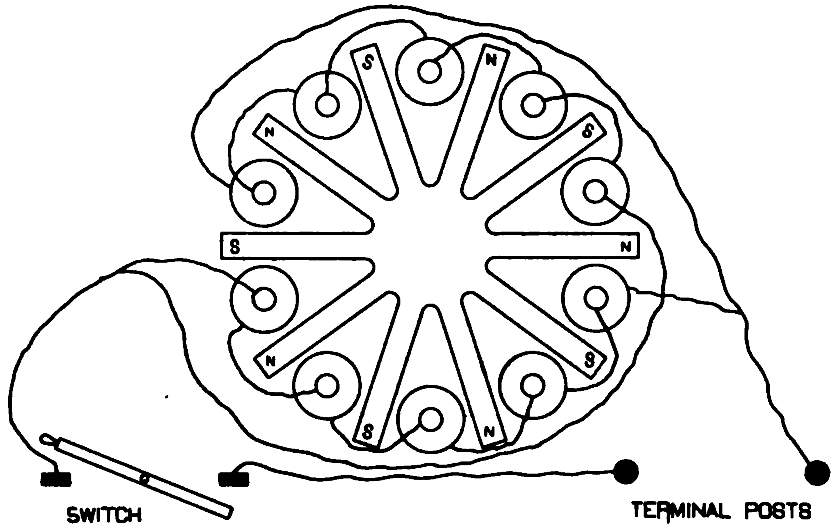
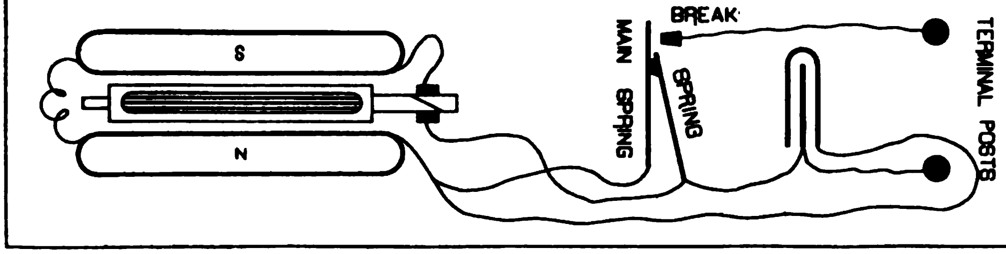


FIG. 3 SIEMENS SPARK MACHINE.



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Although this is a neat, ingenious, and serviceable instrument, it is now superseded, at least in this country, because it can be used neither with low tension nor with very high tension fuzes.

The Beardslee Machine.—This instrument, patented in 1859 and 1863, is similar in principle to that of Wheatstone, but is larger and more powerful. It was much used during our late civil war, in which it justly won a high reputation; but it is now superseded by later devices, for the same reason as the Wheatstone exploder.

The machine (Plate XXIV, Fig. 2) derives its power from a stellar cast iron magnet, having ten poles radiating from the centre and alternating in polarity. The axis is central, and perpendicular to the horizontal plane of the magnets, and is so geared as to admit of rapid revolution, four turns of the magnet to one of the crank. To insure solidity, the spaces between the magnets are sometimes filled by wooden wedges, the whole bound together by a brass tire.

Immediately under this magnet is placed a soft iron ring of equal diameter. Ten pins of soft iron rise from this ring, so placed that when one is covered by a magnet pole all the others are so likewise. These pins are the cores of coils of moderately fine insulated wire, each having a resistance of 110 ohms. As the crank is revolved, the motion of the magnet poles causes a rapid reversal of polarity in these cores, and thus generates a succession of alternating currents of electricity in the coils. The latter may easily be coupled, as desired, to produce high or low potential; *i. e.*, in a continuous series for high, and in multiple arc for low potential. The usual arrangement is two groups of five coils each. Convenient terminal posts are arranged to receive the leading wires, and a switch is added, to allow a high speed of revolution before sending the current into the exterior circuit containing the fuze.

The apparatus is held together by a stout iron frame, permanently encased in a box 18 by 18 by 14 inches, weighing 115 pounds.

Like other instruments of its class, the Beardslee machine exacts a certain conductivity in its fuze. The Abel explodes readily with it; and Captain Beardslee, son of the inventor, has devised a special type (page 208), consisting essentially of a lead pencil mark connecting the leading wires. Fine powder packed on this line is ignited by the heat developed by the electricity. This fuze is claimed to have been fired by the machine at a distance of 240 miles, through an ordinary telegraph line. In submerged cable, the range is of course far less.

In fine, Beardslee's machine is a strong, serviceable instrument, little likely to get out of order; but it is too heavy, and it cannot be used with the best fuzes now in the market in this country.

The Gramme Machine.—This instrument represents the latest and most perfect form of magneto-electric apparatus, for it eliminates the troublesome commutator, and can supply a current as uniform as that of the best voltaic battery.

The principles of its construction are equally applicable, whether permanent magnets or electro-magnets on the dynamo plan are employed. The former are usually selected for hand machines, and the latter for larger apparatus designed to produce the electric light, or to effect the deposition of metals.

The sample of the hand machine in the School of Submarine Mining at Willets Point is intended for laboratory use. It weighs 67 pounds, and occupies a space of 14 by 13 by 25 inches in height.

The permanent magnet is of the Jamin horseshoe type, composed of twenty separate very thin plates, the whole aggregating only 0.8 inches in thickness, and possessing extraordinary power. Between its poles a ring of soft iron is caused to revolve by a crank so geared as to give 10 revolutions for each turn. A speed of 2,300 revolutions per minute can be given for a short time, and 1,400 are easily maintained.

The ring is wrapped at right angles to its plane by thirty small coils of copper wire, No. 19 B. W. G., connected in series in an unbroken circuit. Each junction between two coils is soldered to a thin strip. These strips are insulated from each other and from the axis of the ring, around which they are secured so as to form an external covering. Two bundles of fine wire are placed, like the springs of a commutator, so as to touch in succession each of these strips as the axis revolves, the points of contact being opposite each other and midway between the poles of the magnet. The bundles are connected by insulated wire with terminal binding posts designed to receive the leading wires.

The theory of the apparatus is simple. The soft iron ring revolves in the magnet field, but *its poles remain fixed*, each adjacent to the pole of the magnet to which it owes its existence. The whole arrangement is, therefore, similar to a series of connected coils through which a bar magnet is passed. By the theory of magnetic induction, two equal and opposing currents are thus generated in the coils of the machine, their points of opposition being where the bundles of wire touch the circuit. Electrically, therefore, the thirty coils are like thirty battery cells coupled in two series of fifteen cells each, with the end cells united in opposition, zinc to zinc and coke to coke. Hence, if the exterior circuit be closed, the bundles of wire simply conduct into it the united current of the two series of cells; if it be open, the two currents neutralize each other.

It has been well established by experiment that the electro-motive force of this machine is proportional to the speed of revolution, at least within the limits of practice. A set of measurements was made in March, 1876, to determine the numerical values of the constants pertaining to the individual instrument at Willets Point, in the general equation:

$$C = \frac{E}{R_{,} + R_{,,}} = \frac{A\,T}{R_{,} + R_{,,}}$$

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In this expression, C denotes the strength of current in webers; E, the electromotive force in volts; T, the number of revolutions of the armature per minute (ten times the number of turns of the crank); $R_{,}$, the internal resistance in ohms (measured between the terminals designed for the leading wires); $R_{,,}$, the resistance in ohms of the external circuit; and A, a constant for the individual instrument.

The quantities $R_{,}$ and $R_{,,}$ were determined by a standard Wheatstone bridge; the former was 0.650 ohms, and the latter (for the circuit used in the measurements) 0.163 ohms. It remained to deduce the value of A from measured values of C and E corresponding to a series of values of T. By the method adopted, five operators were required; but since all the variables were measured, the accuracy of the final result admitted of an absolute check.

The external circuit included a Helmholtz-Gaugain galvanometer of which the weber coefficient was accurately known, enabling C at any instant to be deduced from the observed deflection.

Another circuit led from the terminals of the instrument through a trigger key, a standard half microfarad condenser and a Thomson galvanometer, so as to admit at any instant of the application of Law's method to the determination of the part of the electro-motive force ($E_{,}$) consumed in overcoming the external resistance. The constant of this galvanometer in volts was derived from two Clark cells freshly set up. Since this second circuit was never closed, it could form no shunt.

The crank was turned steadily by a trained assistant at various rates of speed, the number of turns per minute being estimated by the aid of a chronometer.

The mode of operating was to bring the Gaugain galvanometer to a steady deflection by revolving the crank at the proposed speed; and then, at the word, to note the number of turns in ten seconds, record the galvanometer deflection, and determine the corresponding value of $E_{,}$ by springing the trigger key.

The beautiful steadiness of the current generated by the machine enabled good readings to be obtained, notwithstanding the difficulty of securing a uniform rate of revolution by hand. This is apparent from the following table:

Observations with the Gramme machine.

Number of experiment.	Observed.		Measured C.			Computed C.	Difference.
	T	$E_{,}$	By Gaugain.	$\frac{E_{,}}{0.163}$	Mean.	$C = \frac{0.0045\,T}{0.65 + 0.163}$	
		Volts.	*Webers.*	*Webers.*	*Webers.*	*Webers.*	*Webers.*
1	540	0.61	3.73	3.73	3.73	3.00	+ 0.73
2	840	0.80	4.76	4.91	4.83	4.65	+ 0.18
3	1,050	0.90	5.85	5.52	5.69	5.80	− 0.11
4	1,260	1.09	6.88	6.69	6.79	6.97	− 0.18
5	1,380	1.25	7.21	7.67	7.44	7.63	− 0.19
Mean			5.69	5.70	5.69	5.61	0.28

The value adopted for A, viz, 0.0045, was derived from these experiments by a rigid analysis, and the table sufficiently confirms its accuracy. Hence, for the general equation of this individual instrument:

$$C=\frac{0.0045\ T}{0.65+R_{,,}}$$

Since it is easy to give 1,400 revolutions per minute to the armature, and, by vigorous effort, 2,300 per minute, the electro-motive force usually ranges from 6.5 to 11 volts.

Experiment with this instrument has shown that ten service platinum fuzes united in series can be exploded on short circuit; and that a single fuze can be fired through a resistance of about 24 ohms.

The apparatus can also be used for any purpose where a steady current like a battery is desired, provided only that the crank be turned at a uniform rate. By sending a moderate battery current through the coils, a motion of the crank is produced in the reverse direction to that required to induce the same current by the machine; thus beautifully illustrating the principle of the mutual transformation of electrical and mechanical energy.

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DYNAMO-ELECTRIC APPARATUS.

This class differs from the magneto-electric apparatus, just described, only in the use of electro-magnets instead of permanent magnets to maintain the magnetic field of force requisite to the developement of the electrical currents. In other words, with dynamo machines physical power is employed to generate both the magnetism and the electricity.

The chief advantages of these machines are that they are not liable to deteriorate from the gradual loss of the permanent magnetism, and that with equal weight they can be made far more powerful. On the other hand, they require more physical force.

Their action is certain, because the core of an electro-magnet always retains a slight residual charge of magnetism. The feeble waves of electricity developed by the movement of the armature in this feeble field of force are, if alternating, first caused to move in the same direction by the use of a commutator, and then are passed through the wires enveloping the cores. The intensity of the magnetic field is thus increased; and by mutual action and reaction it soon becomes exceedingly powerful.

One broad distinction between instruments of this class is based upon the mode adopted for maintaining the field of force. Sometimes, as in the Ladd and Hochhausen machines, a certain part of the electrical current is exclusively devoted to this object, the design being to produce a uniform field whatever be the resistance of the working circuit. With such instruments this object will be attained, and the electro-motive force will depend solely upon the speed of revolution and be independent of the resistance of the external circuit, only when a magnetizing current is employed strong enough not only to saturate the cores of the magnets *per se*, but also to overcome the reaction of working currents circulating through the working armature, which tend to reduce the intensity of the field of force and hence to cut down their own strength. With a small external resistance this reaction may be very strong; and, as a matter of fact, both of the machines named fail to accomplish the result intended, when the external resistance is very small. With this kind of apparatus the electro-motive force is an *increasing* function of this resistance.

With certain other instruments, the windings of the field of force magnets form part of the general working circuit, and in this case a strong field and hence a high electro-motive force is only possible when the resistance of the exterior circuit plus that of the windings is not sufficient to cut down the current below the strength requisite to maintain magnetic saturation in the cores. Here the electro-motive force is a *decreasing* function of the external resistance.

For igniting apparatus, a compromise between these two systems is common. The current is first caused to circulate only through the windings of the cores, and, when the latter becomes saturated, it is switched suddenly into the exterior or working circuit containing the fuzes. The effect is very rapidly to cut down its strength, but in the mean time the fuzes have exploded and hence the desired work is accomplished.

From another point of view, dynamo-electric machines may be classified according to the form in which the electrical force is utilized. Thus these instruments may act: (1) by a single wave, strong at first but rapidly losing power; (2) by a succession of waves alternating in direction; (3) by a current more or less unvarying. By the use of a commutator an alternating current may be transformed into one pulsating in a single direction, thus transferring the instrument from class (2) to class (3).

The following tabular classification, based on this analysis, includes the igniting machines now in most common use:

I. Acting by a diminishing wave.	Siemens spark. Farmer. Smith. Laflin & Rand.
II. Acting by a succession of waves, alternating in direction.	Ladd, without commutator.
III. Acting by a continuous current.	Siemens current. Ladd, with commutator. Hochhausen. Gramme.

Of these machines, Siemens spark can be used with either high or medium tension fuzes; Ladd without commutator, only with medium tension fuzes; all the rest are specially designed for low tension, but some of them may be employed with medium-tension fuzes.

A brief description will now be given of these instruments and of their tests.

The Siemens Spark Machine.—This machine (Plate XXIV, Fig. 3) acts upon the principle that soft iron always retains a weak residual charge of magnetism, a fact discovered by Siemens. It is operated by a horseshoe-magnet, which being of soft iron retains only a small magnetic force when not in action. The bars are wrapped with 1,000 ohms of insulated wire, No. 23 B. W. G. When a powerful current of electricity flows through this wrapping, a strong magnetic power is, of course, developed thereby in the bars. The poles are 4.5 inches in length, and nearly envelop between them what is known as a Siemens armature. This consists of a bar of soft iron 4.5 inches long and 2 inches in diameter, grooved longitudinally and wrapped in this groove with 0.2 ohms of rather coarse wire. This armature is pivoted at its extremities, and connected by suitable gearing with an external crank by which a rapid revolution can be given, six turns to one of the crank. The ends of the armature wrapping are attached to the opposite sides of a commutator on one end of the armature bar. Springs connected with the ends of the magnet wrapping touch first one and then the other of these terminals at each revolution of the armature, and thus convey the current generated by the revolution of the armature within the magnetic field, thrown into the same direction by the commutator, through the magnet coils. When the revolution begins this current is feeble; but as the strength of the magnet increases the latter reacts and thus strengthens the current, which in its turn still more strengthens the magnet. Thus in a few seconds both magnet and current become very strong, as is made evident by the increased power required to turn the crank.

To utilize this current a wire passes from one of the springs to an external binding post, touching, *en route*, one of the plates of a small condenser, 0.002 microfarads in capacity. The wire from the other spring, after traversing the coils of the magnet, is attached to the other plate of the condenser and also to a mainspring, and through it to a break which, when mechanically closed, extends the circuit to a second external binding post. This break is regulated by an ingenious device attached to the driving shaft, which after two turns of the crank releases the mainspring and through its agency closes the circuit to the binding post, and instantly after opens the short circuit through which the current had been flowing. The effect is to send through the external circuit a short wave, due to the current and a strong extra current reinforced by the condenser.

This machine is encased in a box, 14 by 7 by 13 inches, the weight of the whole being 52 pounds. It requires a high or medium tension fuze, and throws a spark

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of large quantity and of comparatively low potential. This feature renders it especially fitted for use with good submerged cable, as electrification does not rapidly reduce the volume of the spark below the effective limit. An Abel fuze can easily be exploded by it through a submerged circuit of a couple of miles of good torpedo cable, use being made of the earth for a return circuit. Twelve Abel fuzes, connected in series or in multiple arc, can be exploded on a short land circuit.

From the manner in which this instrument discharges itself through the fuze circuit, it seems altogether improbable that the ratio of the times in equation (68) can be regarded as unity in comparing its strength of current with that of the magneto-electric machines acting by a single wave; and hence that method cannot be safely trusted. As a matter of curiosity, however, the attempt was made; and the result developed the fact that it is exceedingly difficult to obtain uniform discharges. The maximum time in which to excite the magnets is limited by two revolutions of the crank; and this is not enough. Successive trials gave discordant swings to the needle, indicating a range of ten per cent., even when every care was taken to obtain a maximum. The average strength of current seemed to be about 1.5 times larger than that of the Marcus machine, or perhaps about 1,300 microfarads; but, for the reason above stated, no precision can be claimed for these figures.

In using the instrument, care must be observed to *begin the revolutions with the crank in the position where the main spring has just acted*, and to turn as rapidly as possible. If these precautions be neglected much power will be lost.

The Farmer Machine.—This apparatus possesses decided advantages over any other thus far described; not only from the fact that it permits the use of low-tension fuzes, but also because it acts by a very powerful wave of electricity of low potential, which has little tendency to escape through leaks in the leading wires, but yet has sufficient power to explode many charges arranged in series.

The machine is encased in a strong box 13 by 11 by 18 inches in size, the whole weighing 120 pounds. It acts upon the double circuit principle, and is used in combination with a peculiar switch separate from the instrument.

It consists essentially of a large soft cast iron wire-wrapped magnet, a Siemens armature with a suitably geared crank, and the switch.

The armature is 6.5 inches long, and 2.1 inches in diameter, wrapped with copper wire of No. 19 B. W. G. It is geared to revolve about 7.3 times for every turn of the crank, which enables a strong man to give about 1,000 revolutions per minute.

The magnets are wrapped with copper wire of No. 14 B. W. G.

The circuit (Plate XXV, Fig. 1) is peculiar. Starting at one of the terminal posts, the wire passes round the magnets to one spring of the commutator, thence through the armature to the other spring and from that to the other terminal post. Unless, therefore, these external terminals be connected no circuit exists.

The switch, when attached, completes this circuit; and a rapid revolution of the crank then calls for very great strength. By depressing the left-hand key the short circuit is broken, and the current is sent through the fuze and galvanometer back to the instrument. The resistance of the latter, about 100 ohms, protects the former from explosion, and the continuity of the circuit can thus be verified. By depressing first the right-hand key and then the left-hand key the galvanometer resistance is eliminated from the exterior circuit, and explosion ensues.

It will be noted that when the latter key is depressed the current sent through the exterior circuit is reinforced by the extra current developed by suddenly breaking the short circuit, and that a great increase of power is thus secured. Also, that this wave is momentary in character, since the exterior resistance reduces the strength of the current, and hence the magnetism rapidly diminishes. The explosion occurs, however, before this change has time to develope itself.

Perhaps no class of igniting apparatus is more difficult to subject to exact measurement than that to which this instrument belongs The current is first employed to charge the field magnets to saturation and then is suddenly switched through the fuze circuit, which in general has a resistance sufficient to immediately lower the magnetic intensity of the field of force, and hence to rapidly reduce the electro-motive force. On the other hand, this *quasi* breaking of the circuit developes an extra current which for an instant largely increases this element. Notwithstanding this complex change, the current does not cease, and hence the method employed with the Breguet apparatus, equation (68), is not applicable, because the ratio of the times of action certainly cannot be assumed to be unity. In other words, the electro-motive force, and hence the strength of current for successive differentials of time, first increases to an unknown degree and then falls away at a rate which is a function of the external resistance.

Two methods of trial suggested themselves. The first was the same so successfully applied to the Gramme machine; but several causes of uncertainty and inaccuracy could not be eliminated, viz: (1) the exterior circuit employed (3.26 ohms) might or might not be too great to permit a normal developement of the intensity of the field of force magnets; (2) the augmentation of the electro-motive force due to the extra current would certainly be wanting; (3) the difficulty with all Siemens armatures, namely, that the current is pulsating even when turned by the commutator into a single direction, would render the electro-motive force as measured by Law's method variable. Indeed, that element must differ for every position of the contact terminals of the commutator. The changes in electro-motive force are so rapid as hardly to influence the deflection of the heavy needle of the Gaugain galvanometer, but the instantaneous discharge of the condenser measures a particular value and not the mean value which regulates the former. Nevertheless, to obtain some approximate results the method was tested.

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FIG. 1. FARMER MACHINE.

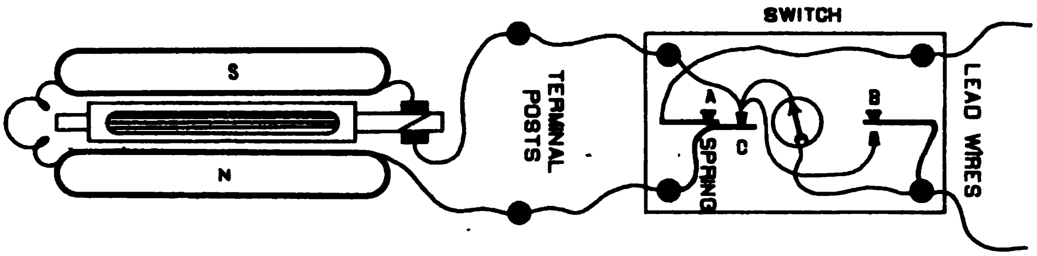


FIG. 2. SIEMENS' CURRENT MACHINE.

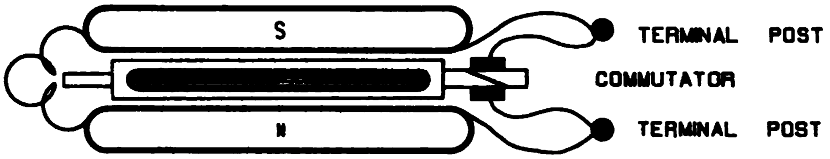
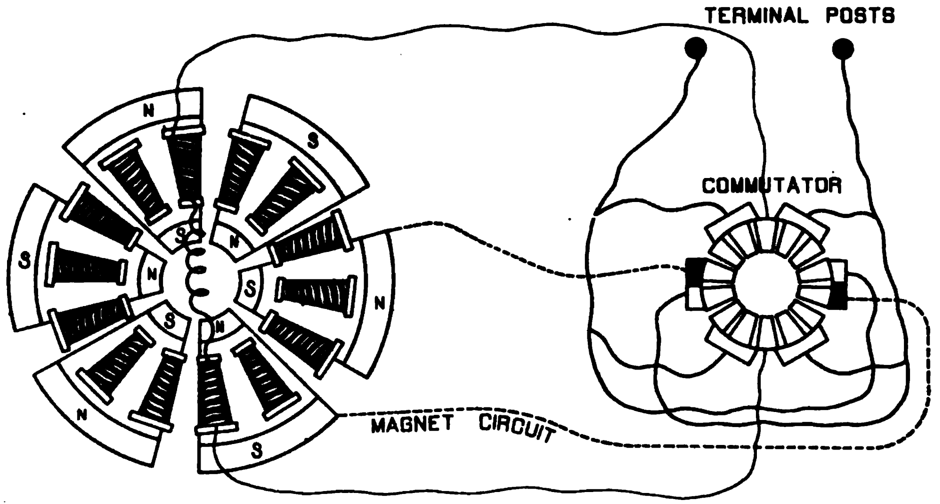


FIG. 3. HOCHHAUSEN MACHINE.



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The internal resistance of the machine being 3.13 ohms, a constant external resistance of 3.26 ohms was selected, and the crank was turned as rapidly as possible by a powerful and well-trained man. The switch, of course, was omitted. The following table exhibits the results obtained:

Observations with the Farmer machine.

Number of experiment.	Observed.		Measured C.		Measured E.	
	T	$E_,$	By Gaugain.	$\frac{E_,}{3.26}$	By Gaugain. (3.13 + 3.26) C	By Law's method. $\frac{3.13+3.26}{3.26} \times E_,$
		Volts.	*Webers.*	*Webers.*	*Volts.*	*Volts.*
1	924	5.70	3.13	1.75	20.00	11.11
2	1,020	14.60	3.13	4.48	20.00	28.47
3	1,056	6.64	3.24	2.04	20.70	12.95
4	1,020	7.20	3.35	2.21	21.41	14.04
Mean			3.21	2.62	20.53	16.64

When the exterior circuit was reduced to 0.14 ohms, 1,000 revolutions of the armature per minute gave a current of 6.40 webers, corresponding to 6.4 (3.13 + 0.14) = 20.93 volts. From this it would appear that the most serious cause of error in this method of measurement is due to *the failure to develop the extra current*, which must considerably raise the electro-motive force available for firing a fuze.

The second method for determining this quantity, devised in 1876, consisted in placing a box of resistance coils, and a low-tension fuze which required a current of 0.5 webers for ignition, in the exterior circuit; sending the wave as usual through this circuit, but at first unplugging enough resistance to prevent ignition; and reducing this amount ohm by ohm until the fuze was fired. This plan rendered it easy to compute from Ohm's law the effective value of E, by multiplying the amount last unplugged plus the resistance of fuze and leading wires (0.87 ohms) plus the internal resistance (3.13 ohms) by 0.5. The following experiments were made in this manner:

First experiment............Last amount unplugged, 60 ohms; electro-motive force, 32 volts.
Second experiment.........Last amount unplugged, 52 ohms; electro-motive force, 28 volts.
Third experiment........... Last amount unplugged, 54 ohms; electro-motive force, 29 volts.
Fourth experiment..........Last amount unplugged, 60 ohms; electro-motive force, 32 volts.
Fifth experiment ....Last amount unplugged, 55 ohms; electro-motive force, 30 volts.
Sixth experiment ....Last amount unplugged, 60 ohms; electro-motive force, 32 volts.
Seventh experiment.........Last amount unplugged, 55 ohms; electro-motive force, 30 volts.
Eighth experiment ....Last amount unplugged, 54 ohms; electro-motive force, 29 volts.
Ninth experiment...........Last amount unplugged, 65 ohms; electro-motive force, 34 volts.
Tenth experiment...........Last amount unplugged, 55 ohms; electro-motive force, 30 volts.

Mean, 30 volts.

Since these results, reached by methods so different, accord so well, it would appear that the full working power of the machine when used to generate a wave, as in igniting low-tension fuzes, may be represented without material error by the following formula:

$$C = \frac{30}{3.13 + R_{,,}}$$

That is, the internal resistance being 3.13 ohms, the machine with 1,000 revolutions per minute will develop for an instant an effective electro-motive force of 30 volts; although not more than 20 volts can be continuously obtained at that speed. The former value is sufficient to explode, near the instrument, about twenty carefully selected service platinum fuzes connected in series; double that number have occasionally been fired at a higher speed.

After such a statement it is quite unnecessary to add that the Farmer machine is admirably suited for river or sea service. Indeed, it has been adopted in the United States Navy for the latter purpose.

One secret of its power lies in the fact that the armature revolves in unusually close proximity to the poles of the magnet. To this fact, and to the judicious winding and the utilization of the extra current, its great power is due.

Like all machines containing a commutator, there is a certain liability that a short circuit may be made between the opposite pieces by metallic dust caused by wear, and, also, that the contact of the springs may become defective. In case of failure these points should be first examined.

The Smith Machine.—This instrument is identical in theory and construction with the Farmer; but it contains an ingenious device for dispensing with the external key, which in blasting is troublesome to a man who for economy is also trying to turn the crank. It is essential to a good development of the power that the short circuit shall be broken when the armature is revolving at full speed. The latter requires vigorous exertion; and the operator is likely to involuntarily slacken his efforts in trying to manipulate the key, thus causing a possible failure if many fuzes are in circuit.

Smith obviates this objection to Farmer's machine by providing a short circuit between the terminals within the case. Part of this circuit consists of a movable arm belonging to an arrangement resembling a gun lock at full cock The trigger is worked by a small armature placed near the soft iron magnet, and is so adjusted as to require the full power of this magnet. When this is developed the trigger snaps, and the mainspring acting on the movable arm suddenly breaks the short circuit, thus shunting an electrical wave through the external circuit. By this device the firing is automatic, and the operator has only to turn the crank, being sure that so soon as he has attained a sufficient speed to develop the full power, the wave will be sent through the fuze. The trigger is reset mechanically by the next revolution of the crank.

Smith's machine is encased in a strong box 13 by 10 by 15 inches high; the whole weighing 77 pounds. The magnet and armature are wound with copper wire—the former of No. 13, and the latter of No. 16, B. W. G. The total internal resistance is 0.56 ohms. The gearing of the crank gives six revolutions of the armature to each turn of the handle.

To determine the electro-motive force generated by the machine, and hence its

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effective equation for the work for which it is designed, the method by fuzes described for the Farmer machine was adopted. About 1,044 revolutions of the armature per minute, the practical limit for which the trigger is set, were given. The internal resistance of the machine being 0.56 ohms, of the fuze at explosion 0.9 ohms, and of the leading wires 0.14 ohms, the constant resistance was 1.6 ohms. Adding the maximum amount in ohms which could be unplugged without preventing explosion, and multiplying the sum by 0.5 webers, gave the following values for E:

First experiment	20 ohms unplugged;	effective E, 10.8 volts.
Second experiment	20 ohms unplugged;	effective E, 10.8 volts.
Third experiment	20 ohms unplugged;	effective E, 10.8 volts.
Fourth experiment	23 ohms unplugged;	effective E, 12.3 volts.
Fifth experiment	25 ohms unplugged;	effective E, 13.3 volts.
Sixth experiment	20 ohms unplugged;	effective E, 10.8 volts.
Seventh experiment	20 ohms unplugged;	effective E, 10.8 volts.
Eighth experiment	21 ohms unplugged;	effective E, 11.3 volts.
Ninth experiment	23 ohms unplugged;	effective E, 12.3 volts.
Tenth experiment	23 ohms unplugged;	effective E, 12.3 volts.
		Mean, 11.55 volts.

Hence for the fuze firing equation of this machine:

$$C=\frac{12}{0.56+R_{,,}}$$

This equation indicates that eight service low-tension fuzes, coupled in series on short circuit, can be fired with certainty; and experiment confirms the prediction. With a considerably larger number, failures are rare. A single fuze can be fired through an external resistance of about 20 ohms.

For military purposes Smith's apparatus is decidedly inferior to the Farmer machine, because the instant of firing is not so perfectly under control; but for ordinary blasting, it evidently possesses merit.

The Laflin & Rand Machine.—This machine, known in the trade as "Magneto No. 3," was patented in March, 1878; and it appears to fulfil more of the conditions desirable for ordinary military service than any of its rivals, while its cost is much less. It has been thoroughly tested at Willets Point, both on land and in boats, and it is now used almost exclusively when from one to five charges are to be fired.

The wooden case is 16 by 8 by 5 inches in size, the total weight being 18½ pounds. A leathern strap handle, with terminals for leading wires and a firing bar arranged for external use, render the instrument portable and convenient.

The internal arrangement will be understood from Plate XXVI, Fig. 1. A Siemens armature revolves between soft iron prolongations of the cores of an electro-magnet. The electricity thus generated is transformed by a commutator from an alternating to a continuous current. The circuit passes from the commutator springs into the adjacent ends of the windings of the magnet. The back-strap ends of the windings of the two halves of this magnet are extended to the terminals for the lead-

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ing wires; and thence to a brass spring and collar where, by platinum contact points, they are joined together, thus completing an interior short circuit tapped by the fuze circuit as a shunt. The magnet is wrapped with 1.76 ohms of cotton-insulated copper wire No. 18 B. W. G., and the armature with 0.92 ohms of No. 21 of the same.

The novelty of the machine lies in the mode of giving rotation to the Siemens armature, and of switching into the fuze circuit the powerful internal current thus induced. Both objects are accomplished by the firing bar, which consists of a square brass rod 14 by ½ by ½ inches, fitted with a wooden handle at one end. The other end passes down into the box. One side is provided with rack teeth engaging in a loose pinion fitting over the armature spindle prolonged. A clutch holds the pinion to the spindle when the rod is descending, but leaves it free when the latter is raised, thus restricting the revolutions of the armature to one direction only. When the firing bar reaches its lowest position, it strikes the brass spring forming part of the interior circuit; and, if in rapid motion, the shock breaks this circuit and thus shunts the current into the fuze circuit. In passing from the top to the bottom of the box the rod causes seven and one-half complete revolutions of the armature; and if the movement be the result of a sudden and strong downward pressure, this is enough to develop a powerful field of force and consequently a powerful electrical current.

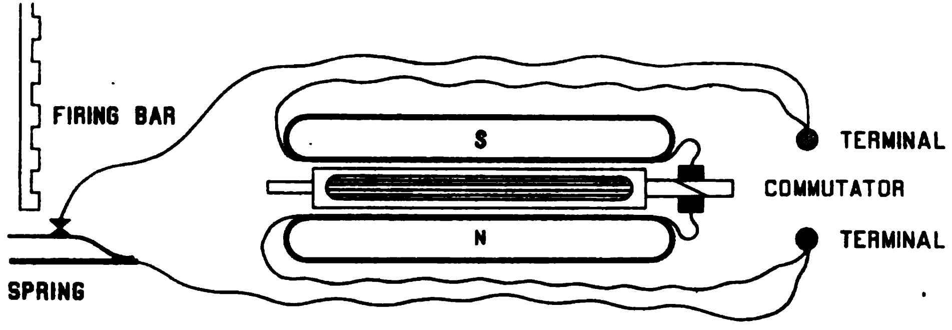
The nature of the wave generated by this instrument is similar to that developed by the Farmer and the Smith machines; and to determine its effective electro-motive force the fuze method of testing described for the former was adopted with the following results.

Observations with the Laflin & Rand machine.

Number of experiment.	Internal resistance and leading wires.	Fuze at explosion.	Amount unplugged.		Measured E. 0.5 ($R_{,} + R_{,,}$)
			Failed.	Exploded.	
	Ohms.	*Ohms.*	*Ohms.*	*Ohms.*	*Volts.*
1	2.71	0.79	30	28	15.75
2	2.71	0.76	33	31	17.23
3	2.71	0.77	31	30	16.74
4	2.71	0.88	33	31	17.25
5	2.71	0.73	28	27	15.22
6	2.71	1.02	33	31	17.36
7	2.71	0.80	30	29	16.25
8	2.71	0.86	31	30	16.78
9	2.71	0.79	31	30	16.75
10	2.71	0.96	30	29	16.33
11	2.71	1.10	33	31	17.40
12	2.71	0.90	32	31	17.30
13	2.71	1.40	37	35	19.55
14	2.71	0.90	33	32	17.80
15	2.71	0.90	30	29	16.30
Mean				30	16.93

These measurements were made in December, 1879, with a new machine just purchased. They indicate that its effective electro-motive force was 16.9 volts. A

FIG. I. LAFLIN & RAND MACHINE.



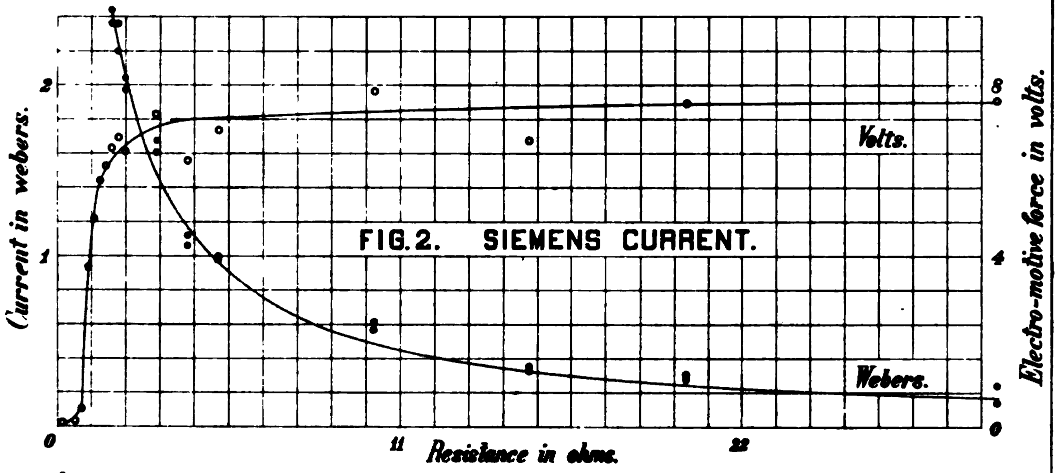


FIG. 2. SIEMENS CURRENT.

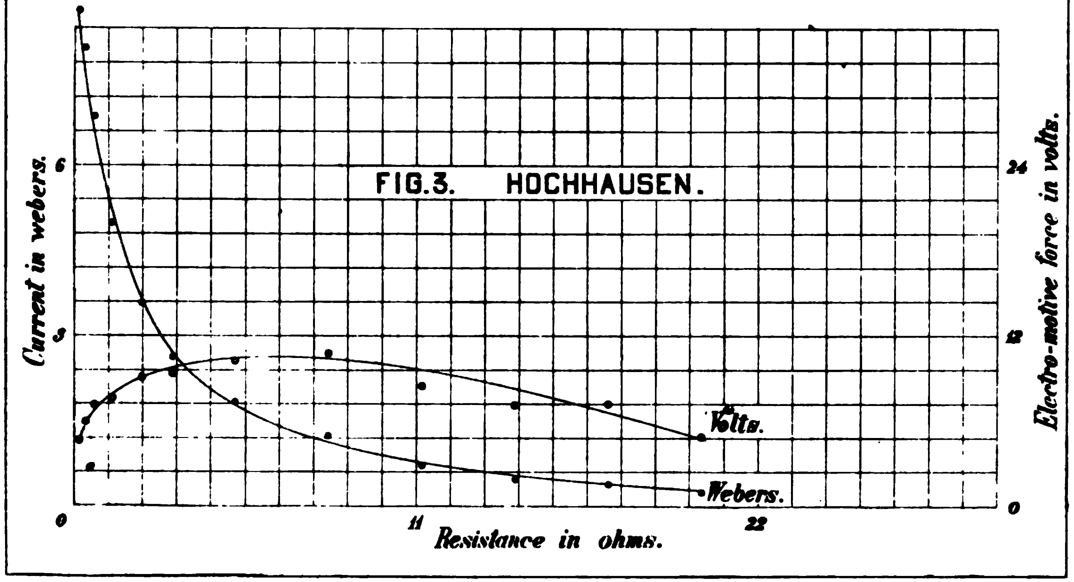


FIG. 3. HOCHHAUSEN.

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similar set made with an instrument received in July, 1878, gave 12 2 volts. Hence, the general working equation for instantaneous action may be regarded:

$$C = \frac{15}{2.7 + R_{\prime\prime}}$$

Assuming that 0.9 ohms is the usual fuze resistance at explosion, and that a minimum current of 1.5 webers is needful to ensure explosion when coupled in series, this equation indicates that 8 fuzes may be fired on short circuit. Experiment confirms this inference—seven fuzes and eight fuzes being thus fired successfully, while with ten in circuit several fail. The instrument, therefore, may be trusted to fire five adjacent guns simultaneously, allowing 2.5 ohms for the resistance of the leading wires. A single fuze may be fired through about 30 ohms.

The mechanism is strong and not likely to get out of order. The only points requiring attention are that no dirt be allowed to collect between the platinum contact points of the break circuit spring; that no metallic dust bridge the cuts in the commutator; and that the spindle bearings, front and rear, be occasionally oiled. By removing a few screws the box may readily be opened for these objects.

The Ladd Machine.—This instrument is designed for laboratory use rather than for practical service, and accordingly is not encased. It occupies a space of 22 by 14 by 23 inches high, and weighs 119 pounds. It was one of the earliest forms of dynamo-electric apparatus, being exhibited at the Paris Exposition of 1867.

It consists of a soft iron magnet wound with copper wire of No. 13 B. W. G. The poles nearly envelop a double Siemens armature, composed of two separate armatures abutting end to end on a common axis, the planes of the windings making right angles with each other. The total length of the compound armature is 11 inches. The separate parts are of unequal length, but both are wound with copper wire of No. 13 B. W. G. The larger or working armature has a resistance of 0.14 ohms. Two separate commutators are placed at the opposite ends of the axis.

The circuit of the smaller armature is permanently restricted to the magnet coils, and its sole work is to create and maintain a strong magnetic field for generating the current in the larger or working armature.

The circuit of the latter passes straight from the contact springs of the commutator to terminal binding posts designed to receive the leading wires of the external circuit. The commutator springs of the working armature can be adjusted so as to draw off at pleasure a direct or an alternating current, thus bringing the instrument under Class III or Class II, as may be desired.

The mechanical details of the gearing are novel and ingenious. One turn of the crank gives 15 5 turns of the compound armature; and a speed of 1,000 revolutions per minute for the latter can easily be maintained.

To determine the power of the Ladd machine in electrical units, resort was had in March, 1876, to the method of testing with tangent galvanometer and condenser combined, which has been fully described when discussing the Gramme machine. The following results were obtained by this plan:

Observations with the Ladd machine.

Number of experiment.	Measured values of—				Computed E.			Remarks.
	T	$R_{,,}$	$E_{,}$	C	$C(R_{,}+R_{,,})$	$\frac{E_{,}(R_{,}+R_{,,})}{R_{,,}}$	$E_{,}$	
		Ohms.	*Volts.*	*Webers.*	*Volts.*	*Volts.*	*Volts.*	
1	1,023	∞	+ 7.4	0.00	...	......	+ 7.4	The internal resistance ($R_{,}$) is 0.14 ohms.
2	1,023	∞	+ 4.3	0.00	....	......	+ 4.3	
3	1,116	∞	+ 2.5	0.00	....	......	+ 2.5	
4	1,023	∞	+ 2.5	0.00	....	......	+ 2.5	
5	1,023	∞	+ 7.8	0.00	....	......	+ 7.8	
6	1,116	∞	+ 7.6	0.00	....	......	+ 7.6	
7	1,023	∞	+16.5	0.00	....	......	+16.5	
8	1,023	∞	+ 4.1	0.00	....	......	+ 4.1	
9	1,116	∞	− 2.1	0.00	....	......	− 2.1	
10	1,023	∞	+ 4.1	0.00	....	......	+ 4.1	
11	930	1.47	+ 6.2	2.40	3.84	+ 6.8	......	
12	837	1.47	− 1.5	2.32	3.71	− 1.7	......	
13	1,023	0.77	+ 5.7	3.12	2.74	+ 6.8	......	
14	1,209	0.77	− 0.2	3.12	2.74	− 0.2	......	
15	930	0.77	+ 3.7	3.07	2.79	+ 4.4	......	
16	1,023	0.77	+ 4.5	3.07	2.79	+ 5.4	......	
17	1,023	0.77	+ 3.9	3.07	2.79	+ 4.7	......	
18	1,116	0.77	− 1.7	2.97	2.67	− 2.0	......	
19	1,023	0.77	+ 5.6	2.82	2.57	+ 6.7	......	
20	837	0.77	+ 4.6	2.92	2.66	+ 5.5	......	
21	930	0.77	+ 3.1	2.97	2.67	+ 3.7	......	
22	930	0.77	− 1.0	2.97	2.67	− 1.2	......	
23	1,116	0.17	+ 1.4	2.62	0.81	+ 2.8	......	
24	1,023	0.17	+ 1.4	2.62	0.81	+ 2.8	......	
25	930	0.17	0.0	2.67	0.83	0.0	......	
26	930	0.17	− 0.5	2.67	0.83	− 1.0	......	
27	930	0.17	− 0.9	2.72	0.84	− 1.8	......	

The last three columns of this table merit special attention. The first is derived from the uniform deflection of the needle of a tangent galvanometer, around the coils of which the current was flowing. This needle was so heavy that it failed to respond to instantaneous changes in the strength of current, and thus measured the *average* current, and hence indirectly the *average* electro-motive force developed. The last two columns are derived from the discharge of a condenser; and thus represent the subtile variations in electro-motive force caused by the fact that the current is not uniform, but simply a succession of waves following each other in the same direction. That the numbers are constantly varying, and not infrequently negative, suggests an explanation for what is well known in practice, viz: that apparatus which requires a commutator is not so well suited for the deposition of metals as the Gramme class.

Another important principle connected with dynamo-electric apparatus is illus-

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trated by this table. The current generating the magnetic field of force is distinct from that available for external work; but still the electro-motive force of the latter is plainly an increasing function of the external resistance. This should be so, because when a strong current is flowing through the working armature it reacts powerfully by induction, and thus reduces the intensity of the magnetic field and hence is itself reduced. With a large external resistance, and hence a feeble current through the working armature, the reaction is less. The following table, abstracted from the last, places this matter in a clear light; and proves that for use with a small external resistance, the field of force armature in the Ladd machine might advantageously be made larger and stronger:

Analysis of last table.

Number of observations.	External resistance.	Electro-motive force.		Remarks.
		By Gaugain.	By condenser.	
	Ohms.	*Volts.*	*Volts.*	
5	0. 17	0. 82	0. 56	
10	0. 77	2. 71	3. 38	
2	1. 47	3. 78	2. 55	Too few observations with condenser.
10	∞	....	5. 47	

It remains to consider what value of E should be adopted in an equation to represent the fuze igniting power of this machine.

The external resistance in fuze firing is usually large enough to ensure a strong field of force, and hence a relatively high value of E, the numerical measure of which it was thought could best be fixed by direct experiment. At about 1,000 revolutions of the armature per minute, the service fuze exploded through 14 ohms unplugged in the circuit, and failed through 15 ohms. Hence:

$$E = 0.5\ (0.14 + 14.8) = 7.5 \text{ volts.}$$

This value is perfectly consistent with the foregoing tables, and has been adopted; giving for the fuze firing formula, with 1,000 revolutions per minute:

$$C = \frac{7.5}{0.14 + R_{\prime\prime}}$$

This equation indicates that the machine will fire, with certainty, five service low-tension fuzes coupled in series on short circuit, which is confirmed by experiment. A single fuze can be fired through a resistance of about 14 ohms.

The Siemens Current Machine.—This instrument is designed to fire single low-tension fuzes without a discharging key. It is exceedingly neat and portable, weighing only 32 pounds. The case is 9 by 7 by 12 inches high.

The apparatus consists of a soft iron magnet wrapped with 1.95 ohms of copper wire of No. 17 B. W. G. The poles nearly envelop a Siemens armature wrapped with 0.49 ohms of the same gauge of copper wire. The crank is so geared to the armature as to give 10.8 revolutions for every turn, enabling a speed of 1,500 revolutions per minute to be readily obtained.

The electrical connections (Plate XXV, Fig. 2) constitute the peculiar feature of the machine. Each terminal binding post is united directly with one end of the magnet wrapping, and with one of the commutator springs. The external circuit thus constitutes a shunt to the magnet circuit. From the general theory of derived circuits, the effective current in the exterior circuit ($C_{,,}$) may be expressed by the following formula, when the armature is revolving steadily and with sufficient speed to produce magnetic saturation in the magnet cores. The resistance in ohms in the magnet circuit is represented by *m*:

$$C_{,,}=\frac{E}{R_{,}+\dfrac{m\,R_{,,}}{m+R_{,,}}}\times\frac{m}{m+R_{,,}}$$

This peculiar arrangement of the magnetizing and of the working circuits rendered the machine an interesting subject of study; and, in March, 1876, its power was tested with considerable care. The combined galvanometer and condenser method used with the Gramme, gave the following results. The formulæ by which the values of E and $C_{,,}$ were computed, are discussed below—see also Plate XXVI.

Observations with the Siemens current machine.

Number of experiment.	Measured values.				Computed values.		Difference in $C_{,,}$	Remarks.
	T	$R_{,,}$	$E_{,}$	$C_{,,}$	E	$C_{,,}$		
		Ohms.	*Volts.*	*Webers.*	*Volts.*	*Webers.*	*Webers.*	
1	842	∞	+ 0.3	....	....	....	....	$R_{,}$ is 0.49 ohms; *m* is 1.95 ohms.
2	1,037	∞	−22.2	....	....	....	....	
3	1,296	∞	+19.9	....	....	....	....	
4	1,296	∞	+11.2	....	....	....	....	
5	1,231	∞	+10.5	....	....	....	....	
6	1,296	∞	+16.7	....	....	....	....	
7	1,296	∞	+11.2	....	....	....	....	
8	1,296	∞	+13.2	....	....	....	....	
9	1,296	∞	+ 9.2	....	....	....	....	
10	1,231	∞	+ 4.5	....	....	....	....	
11	1,296	∞	+ 4.5	....	....	....	....	
12	1,361	∞	+ 3.0	....	....	....	....	
13	1,361	∞	+ 1.7	....	....	....	....	
14	1,296	∞	+ 9.2	....	....	....	....	
15	1,296	∞	+ 0.3	....	....	....	....	
16	1,620	30.18	+ 5.9	0.25	7.65	0.17	+ 0.08	
17	1,361	30.18	− 0.5	0.15			− 0.02	
18	1,361	20.18	0.0	0.28	7.59	0.25	+ 0.03	
19	1,490	20.18	+ 7.0	0.31			+ 0.06	
20	1,426	15.18	+12.0	0.36	6.72	0.33	+ 0.03	
21	1,296	15.18	−15.0	0.33			0.00	

Observations with the Siemens current machine—Continued.

Number of experiment.	Measured values.				Computed values.		Difference in $C_{,,}$	Remarks.
	T	$R_{,,}$	$E_{,}$	$C_{,,}$	E	$C_{,,}$		
		Ohms.	*Volts.*	*Webers.*	*Volts.*	*Webers.*	*Webers.*	
22	1,361	10.18	+28.9	0.57	7.87	0.49	+ 0.08	
23	1,426	10.18	+ 3.0	0.62			+ 0.13	
24	1,361	5.18	− 0.3	1.00	6.97	0.94	+ 0.06	
25	1,296	5.18	+ 6.2	1.00			+ 0.06	
26	1,361	4.18	0.0	1.06	6.23	1.22	− 0.16	
27	1,426	4.18	− 0.3	1.12			− 0.10	
28	1,361	3.18	− 0.5	1.68	7.35	1.48	+ 0.20	
29	1,361	3.18	+10.5	1.61			+ 0.13	
30	1,361	2.18	+ 7.7	2.04	6.46	2.06	− 0.02	
31	1,361	2.18	− 0.3	1.97			− 0.09	
32	1,490	1.98	+ 5.7	2.20	6.77	2.24	− 0.04	
33	1,685	1.98	+13.7	2.36			+ 0.12	
34	1,490	1.78	− 1.5	2.36	6.54	2.44	− 0.08	
35	1,361	1.78	− 3.7	2.45			+ 0.01	
36	1,490	1.58	+ 1.2	2.45	6.10	2.70	− 0.25	Magnetic field losing strength.
37	1,490	1.58	− 0.3	2.49			− 0.21	
38	1,490	1.38	+ 7.7	2.62	5.77	2.98	− 0.36	Do.
39	1,490	1.38	+ 3.4	2.58			− 0.40	
40	1,685	1.18	− 3.0	2.49	4.87	....	......	Weak magnetic field.
41	1,490	1.18	+ 5.2	2.45			......	
42	1,620	0.98	−12.5	2.28	3.74	....	......	Do.
43	1,685	0.98	+ 3.7	2.08			......	
44	1,426	0.78	+ 0.5	0.18	0.43	....	......	Do.
45	1,620	0.78	......	0.41			......	
46	1,490	0.58	+ 0.1	0.11	0.14	....	......	Do.
47	1,361	0.58	......	0.12			......	
48	1,490	0.18	......	0.15	0.11	....	......	Do.
49	1,490	0.18	......	0.15			......	
Mean of common points....................				1.41	0.68	1.44	0.11	

The efficacy of this machine must evidently depend upon a skilful application of the laws of derived circuits, since the strength of the magnetic field of force is governed by the amount of current which is drawn naturally through the coils; and hence, in winding the magnets, the resistance of the latter should be regulated by the probable resistance to be used in the fuze circuit.

The conditions to be fulfilled are plainly indicated by the general formula given above. The only unknown quantity in its second number is E. This must evidently be an increasing function of $R_{,,}$, since, if that quantity be zero, no current will circulate through the magnet coils, and E must be zero. The measurements were planned to reveal the law of increase. The direct determination by the condenser failed, by reason of the pulsating nature of the current given by the Siemens armature—which has already been pointed out in discussing the Ladd and Farmer machines. This difficulty was obviated by computing the value of E for each observation by the general formula above given; in which it is the only unknown quantity. The results are shown in the sixth column, and they exhibit the law very plainly. Until the exterior circuit is increased to about 0.8 ohms, no magnetic field of force is produced. Above this amount, E increases at first very rapidly and then more slowly until the exterior circuit becomes about equal to the resistance of the magnet coils (1.95 ohms), when it becomes sensibly constant and equal to obout 6.8 volts.

Hence the working equation may be found by assuming E to be 6.8 volts, substituting the known values of the other constants in the general formula, and reducing. Ignoring decimals, this method gives the following equation for this individual machine:

$$C_{''}=\frac{10+5\,R_{''}}{R_{''}^{2}+2\,R_{''}+1}=\frac{5(R_{''}+2)}{(R_{''}+1)^{2}}$$

The values of $C_{''}$ in the seventh column of the foregoing table are computed by this formula, and their remarkable agreement with the corresponding measurements shown by the fifth and eighth columns, establishes the fact that the machine works strictly in accordance with its mathematical theory.

The largest available current at a speed of 1,500 revolutions of the armature is about 2.6 webers, showing (since the two circuits are then equal in resistance) that the magnet requires a like current to develop the full power of the machine, which then generates about 5 webers. A service platinum fuze can be exploded through about 13 ohms.

If it be desired to fire several fuzes simultaneously with this apparatus, an exterior circuit of about 1.5 ohms, so arranged as to be readily broken to shunt the current through the group, should be provided.

From the foregoing data, and general electrical principles, it would be easy to compute the dimensions of a machine of this pattern to supply any desired current.

The Hochhausen Machine.—This apparatus, the most recently devised of any to be here described, is an ingenious, compact, and serviceable instrument. It weighs eighty-four pounds, and is contained in a box 12 by 11 by 12 inches in size.

It contains (Plate XXV, Fig. 3) six soft iron electro-magnets, so secured that the poles lie on two concentric circles and alternate in polarity. The coils of these magnets are united in series, the terminals being connected to two opposite commutator half-plates, which will soon be described. The wire is of copper, of No. 18 B. W. G., with a total resistance of 12.3 ohms, or about 2 ohms to each magnet. The poles project about 2 inches beyond their coils.

An axis, central to the magnets, is geared to a crank so as easily to give a speed of about 425 revolutions per minute—3.2 turns of the axis to one of the crank.

A circular plate of brass, perpendicular to this axis, is rigidly attached to revolve just in front of the magnetic poles. It carries fourteen soft iron armatures, so placed as to pass close between and to overlap the projecting poles of the magnets. These armatures are each wrapped with 1.1 ohms of copper wire of No. 20 B. W. G. They

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are coupled by their inner wires, two and two, on diameters of the brass circle, thus forming seven separate circuits, each containing two coils which must always be approaching and receding from similar magnetic fields at the same time; they are wound so as to send their induced currents in the same direction, thus making each of the seven circuits analogous to two cells coupled in series. The outer wires of the coils are attached to insulated brass segments on the axis, each pair on opposite sides of the axis.

The commutator is a novel feature of the machine. It consists of six insulated metallic plates placed opposite the intervals between the magnets on a sheet of ebonite, and abutting against springs projecting from the revolving ends of the segments The first, third, and fifth of these plates are united by a brass strip and connected with one of the terminal binding posts. The other three in like manner are extended to the other post. The width of the plates is sufficient to slightly overlap two adjacent segments, which give currents moving in the same direction, since one is leaving and the other other approaching magnets of opposite polarity.

To supply the magnetic fields, two of the opposite commutator plates are each cut into two insulated halves; and the current from each of the two coil circuits is thus successively sent at each revolution for an instant through the magnet circuit, which as already stated is connected with two of the opposite half commutator plates. The current drawn off by the other half plates reinforces the main current, as above indicated.

Since the different pairs of coils at any given instant are moving in different positions in the magnetic field, some of the induced currents are increasing as others are decreasing. Increased steadiness in the combined current is thus secured.

In fine, then, the electrical arrangement is analogous to a battery containing seven groups of two cells each. One group feeds the magnets; and the other six, connected in multiple arc, supply the working current for the exterior circuit.

The method adopted (April, 1876) for testing this instrument was that used with the others of its class, and which has been fully detailed when discussing the Gramme machine (page 275). The following table exhibits the results, R, being 0.37 ohms. The figures indicate certain peculiarities of the machine which require graphic illustration, and this has been attempted by figure 3, Plate XXVI. By studying these curves in connection with the text following the table, and comparing them with those of figure 2 of the same plate, which illustrates the working of the Siemens current machine, a clear idea can be formed of the practical effect of the difference in electrical principles embodied in these apparatus.

Observations with the Hochhausen machine.

Number of experiment.	Measured values.				Measured E.			Remarks.
	T	$R_{,,}$	$E_{,}$	C	By Gangain. $(0.37 + R_{,,})C$	By Law's method. $\frac{0.37 + R_{,,}}{R_{,,}} \times E_{,}$	$E_{,}$	
		Ohms.	*Volts.*	*Webers.*	*Volts.*	*Volts.*	*Volts.*	
1	425	∞	10.2	....	....	....	10.2	
2	425	∞	1.9	....	....	....	1.9	
3	425	∞	3.5	....	....	....	3.5	
4	425	∞	2.2	....	....	....	2.2	
5	730	∞	16.4	....	....	....	16.4	
6	690	∞	0.0	....	....	....	0.0	
7	690	∞	12.9	....	....	....	2.9	
8	425	20.18	12.9	0.24	4.93	13.1	....	
9	425	17.18	20.8	0.41	7.20	21.2	....	
10	425	14.18	14.3	0.49	7.12	14.7	....	
11	425	11.18	21.0	0.74	8.53	21.7	....	
12	425	8.18	17.5	1.27	10.83	18.2	....	
13	425	5.18	12.7	1.86	10.28	13.6	....	
14	425	3.18	7.8	2.66	9.39	8.7	....	
15	425	2.18	....	3.50	9.08	....	....	
16	425	2.18	12.4	3.57	9.03	14.5	....	
17	425	1.18	6.6	5.00	7.65	8.7	....	
18	425	0.68	6.0	6.88	7.09	9.3	....	
19	425	0.38	3.6	8.08	5.90	7.1	....	
20	425	0.18	2.3	8.74	4.63	7.0	....	
21	400	2.44	....	2.71	....	....	....	
22	400	5.44	....	2.11	....	....	....	
23	320	0.94	....	3.68	....	....	....	
24	320	1.94	....	1.98	....	....	....	

This table indicates some curious facts respecting the working of the instrument As usual, an increase in the speed of rotation of the armature gives an increased current, which implies an increased electro-motive force; but no attempt was made to reduce this law to figures, on account of the peculiar changes indicated in the latter quantity as the external resistance was increased, the speed remaining the same.

The condenser measurements show a greater constancy in E than is usually obtained with a Siemens armature, but one far below that given by the Gramme class; but the variation revealed by the first seven observations, when the external circuit was open, proves that very numerous records would be needed to arrive at definite conclusions as to the numerical value of the electro-motive force by this plan.

The galvanometer measurements are accordant among themselves, and indicate the usual law of decrease in current as $R_{,,}$ increases. The different values of E given by this method, however, are peculiar and not easily explained. They reveal a normal increase as the external resistance increases, up to about 8 ohms; when a maximum (about 11 volts) appears to be reached. Beyond this point the electromotive force gradually falls off, until at 20 ohms it is about the same as on short cir-

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cuit. This anomalous result is confirmed by the condenser records, which suggest a very low value for an open exterior circuit, when, by the usual law governing double current machines, it should be high.

The power of the instrument for firing low-tension fuzes is the following: With 425 revolutions of the armature, a single service fuze may be exploded through a resistance of about 15 ohms; and with the maximum speed, 700 revolutions, through 35 ohms. A still further increase of power may be obtained by using a key so arranged as to break an external circuit (about a couple of ohms) when the maximum speed has been secured, and thus to switch the current, reinforced by an extra spark, into the fuze circuit. If fuzes in series are to be fired, this plan should always be employed; but the machine is hardly suited for such work.

The Modified Wild Machine.—This instrument was of quite a different character from any of the preceding, being driven by a steam engine and designed to supply a current of enormous quantity. It was made by the Laflin & Rand Powder Company, and was tested at their works at Wayne, N. J., in March, 1876.

It weighed 900 pounds, and occupied a space of 34 by 14 by 42 inches in height. It was claimed that with 4-horse power, about 1,500 revolutions per minute could be given when working on short circuit.

In principle it was identical with the Wild machine; but the permanent magnets were replaced by an electro-magnet actuated by a small Siemens armature, which supplied the current for creating the two independent magnetic fields of force in which it and the working Siemens armature revolved. Both armatures were geared by separate belts to the shafting, and were, of course, quite distinct from each other.

The small armature was 10 inches long by 2½ inches in diameter, and was wound with Lake Superior copper wire of No. 12 B. W. G. Its magnet was wound with No. 5, and the main magnet with No. 8 copper wire of the same gauge.

The working armature was 20 inches long by 4 inches in diameter; and was wound with 30 pounds of a square copper rod about 0.2 inches on the edge, and insulated with silk ribbon. Its length was about 190 feet and its resistance, at 54° Fahr., was 0 0428 ohms. The secret of the power of the machine lay in this excessively small internal resistance, which made its whole energy available for the external circuit.

Wheatstone's method was employed to measure the electro-motive force, the standard of comparison being six Daniell's cells freshly set up with pure chemicals, and compared with a Clark standard cell by Law's method. Very long leading wires were used to avoid any magnetic disturbance of the needle of the galvanometer, which was a good instrument, having a resistance of about 30 ohms and a well determined weber coefficient. The following table exhibits the data thus obtained, and a comparison of the results with the indications of the formula given below:

Observations with the modified Wild machine.

Number of observation.	Revolutions per minute. (T)	Resistance of circuit. $(R_{,} + R_{,,})$	Current by galvanometer. (C)	Electro-motive force (E).			Computed E.	Difference.
				Wheatstone method.	$C (R_{,} + R_{,,})$	Grand mean.		
		Ohms.	*Webers.*	*Volts.*	*Volts.*	*Volts.*	*Volts.*	*Volts.*
1	1,460	2150.9	0.0183	34.24	39.36	35.46	34.97	+ 0.49
2	1,460	5150.9	0.0066		33.96			
3	1,120	1550.9	0.0156	28.10	24.19	26.32	26.82	− 0.50
4	1,120	3150.9	0.0079		24.89			

An analysis of the data in the first seven columns of this table proves that, for a large external resistance, this instrument follows the usual law—*i e.*, for ranges usual in practice, the electro-motive force is directly proportional to the speed of revolution of the armature. Its equation appears to be the following:

$$C = \frac{0.02395\ T}{0.043 + R_{,,}}$$

The last two columns show that this equation accords well with the observations. Hence, if the current generated by the small armature be sufficient to maintain a saturated field of force for the working armature when the external resistance is reduced to zero, the machine, at 1,500 revolutions per minute, is capable of yielding under an electro-motive force of about 36 volts the enormous current of 835 webers. It is, therefore, well suited for work requiring great strength of current and comparatively small differences of potential.

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VOLTAIC BATTERIES.

Every class of igniting apparatus heretofore considered requires the act of an intelligent agent to determine the explosion; and most of them call for the continuous expenditure of mechanical power to maintain the needful supply of electricity during any delay that may occur in giving the word to fire.

In the voltaic battery, not only is a reserve fund of potential energy always available for instantaneous use, but also by suitable contrivances the action may be made purely automatic. Human agency and human fallibility are thus in a measure eliminated.

These advantages are decisive in submarine mining, and voltaic batteries will probably never have a rival for this class of work.

The varieties of voltaic cell are very numerous, and they differ among themselves in electro-motive force, in internal resistance, and in constancy of action. For any particular use, therefore, a wide range is offered for judicious selection.

Four distinct classes are needed in the Torpedo Service: (1) Firing batteries, which must possess a high electro-motive force and a low resistance in order to send a strong current through a long length of cable. The action being instantaneous, constancy is of little importance. (2) Signal batteries, which must send a current through the circuit too feeble to ignite the fuze, but sufficiently powerful to operate electro-magnets in the casemate. If the circuit be closed and of low resistance, they must supply a constant current; but, if open, this condition is not essential. (3) Testing batteries, designed for the measurement of resistance and electro motive force. If the former be small, as in the case of conductors, a chief merit is to exact little attention to keep in order; but for insulation tests a high electro-motive force is also an essential condition. For measuring electro-motive force absolute constancy in this element is to be desired. (4) Batteries for the electric light. Here, high electro-motive force, low internal resistance, and great constancy of action are indispensable.

These considerations make it evident that every variety of battery is of interest in the study of submarine mining, and they have received great attention at Willets Point. Although many types are not suited for actual firing, all have an indirect bearing upon the subject, and hence will be treated in this chapter.

The mathematical and chemical theories of the voltaic cell are so well understood that they require no notice here; especially as the whole subject is fully discussed in our Manual for Submarine Mining. Attention, therefore, will be restricted to the experimental researches conducted at Willets Point.

These researches have been directed to determine: (1) the electro-motive force and internal resistance of the several elements; (2) the constancy of the current which can be derived from each type when acting through a circuit suited to its class; (3) the rate of deterioration likely to be developed by service; (4) characteristic peculiarities of the several cells; (5) the best mode of reducing defects which cannot be entirely overcome.

Electro-motive force (in volts) has usually been measured by direct condenser comparisons with standard Clark cells in perfect order. The strength of current (in webers) has been obtained either from the deflections of a Helmholtz-Gaugain galvanometer, of which the coefficient is accurately known, or by a condenser determination of the difference of potential between points of the circuit between which the resistance in ohms was carefully measured. Internal resistance has usually been determined either by Mance's method or by noting with a condenser the fall in potential between the poles, caused by suddenly closing the circuit through a known external resistance. Standard coils (in ohms), made by Elliott Bros., of London, have been employed in all measurements of resistance. In a word, use has been made of none but the best instruments and the best methods.

By modifying the size of the cell and the dimensions and relative positions of the plates, the internal resistance may be made to vary within wide limits. Hence, although the electro-motive force is quite independent of these arrangements, batteries of any particular type may be arranged to serve very different practical purposes.

For this reason each type will be treated by itself, the internal resistance being regarded simply as a basis for subordinate classification.

In like manner, to secure great constancy of action, cells are sometimes set up with the positive and negative plates in different fluids separated by a porous diaphragm. This arrangement increases the internal resistance; but, although chemically very different, it hardly modifies the practical working sufficiently to constitute a primary basis of subdivision.

In a word, to avoid needless repetition in the following analysis, cells closely allied to each other will usually be grouped under a single heading, characteristic of the class.

The Nitric Acid Cell—two-fluid.—When a very strong and constant current is needed—as, for example, to produce the electric light—this class is so much superior to all others as to have no rival.

The zinc, well amalgamated, is placed in a strong mixture of sulphuric acid and water—say one part to eight parts—and the negative plate, separated therefrom by a porous cup, is placed in commercial nitric acid. The cell owes its strength to the high electro-motive force of the combination, and to the very perfect depolarization of the negative plate. The endurance depends upon the volumes of the liquids; and the internal resistance, upon the size of the plates and the material of the porous cup.

The objections to the cell are the stifling fumes of nitric peroxide which rise from the fluid round the negative plate, and the troublesome action of the nitric acid which passes through the porous cup and attacks the coat of mercury protecting the zinc, thus rendering the cleaning and re-amalgamation a tedious process.

There are several varieties of this cell in common use. Thus, if the negative plate be composed of platinum, it is known by the name of its inventor, Grove; and if of carbon, by that of Bunsen. To reduce the fumes, the nitric acid is sometimes filtered through crystals of potassium bichromate, as suggested by Ruhmkorff, a device which for a time serves a useful purpose. Another modification is to mix equal parts of sulphuric acid with the nitric acid, which tends to absorb the water formed by the action of the cell, and thus to preserve the strength of the depolarizing agent. Still another modification is to add to the Ruhmkorff compound one-third its volume of sulphuric acid, with just enough water to dissolve any precipitated chromic acid. These modifications are all improvements upon the simple nitric acid cell.

Three different sizes of Grove cell have been much used in these researches. The electro-motive force of all of them where freshly set up may be considered 2 volts without sensible error.

A compact pattern, made by Ladd, of London, consists of an ebonite cup 2 by 3 by 4.7 inches deep The zinc is flat, but bent so as to enclose a rectangular porous cup of red earthenware, which is thin and easily permeated by the fluid. About 18

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square inches of platinum surface and 40 square inches of zinc surface are immersed in the fluids. The internal resistance of this cell is about 0.15 ohms; the platinum of one cell is held by a clamp to the zinc of the next; and the arrangement is compact, easily manipulated, and capable of furnishing a strong current which will maintain the electric light continuously for three or four hours without fresh acid. The cells are placed by tens in convenient boxes, ten of which coupled in series are well suited for this use in submarine mining.

Another pattern, often used in low-tension fuze testing, consists of a small cylindrical glass jar containing a cylindrical zinc 2.7 inches in diameter and 4 inches deep, exposing 60 square inches to the fluid. A cylindrical porous cup of white earthenware is surrounded by this zinc. The platinum is curved in form, and exposes 16 square inches to the fluid. It is attached to an ebonite cover, which serves in some degree to confine the fumes; and three cells, the usual number, may be used without serious annoyance, near the instruments. The internal resistance of this cell is about 0.08 ohms.

The third pattern was formerly much used in this country for telegraphy. The jar is of glass, 4 inches in diameter and 4 inches deep. The zinc is a stout cylinder, exposing 40 square inches of surface to the fluid; it carries an arm projecting over the next cup, to the end of which a platinum strip is soldered. The latter exposes 4 square inches to the fluid. The porous cup of red earthenware rests within the zinc, and is very permeable. The internal resistance of this pattern is about 0.3 ohms; and the whole arrangement is exceedingly convenient for general laboratory use.

The pattern of Bunsen cell uniformily employed has been that common in our market. The jar is of glass, 6.5 inches in diameter and 9 inches high. The zinc, cylindrical in form, surrounds the porous cup of white earthenware, and exposes 190 square inches to the fluid. The negative plate is a prism of carbon 0.8 by 2 by 9 inches, exposing 42 square inches. It is well to immerse the upper part in melted paraffine for a few minutes, to prevent the infiltration of the acid and the consequent upward creeping of the salts and corrosion of the clamp. The internal resistance of this cell is rather less than 0.1 of an ohm, when freshly set up.

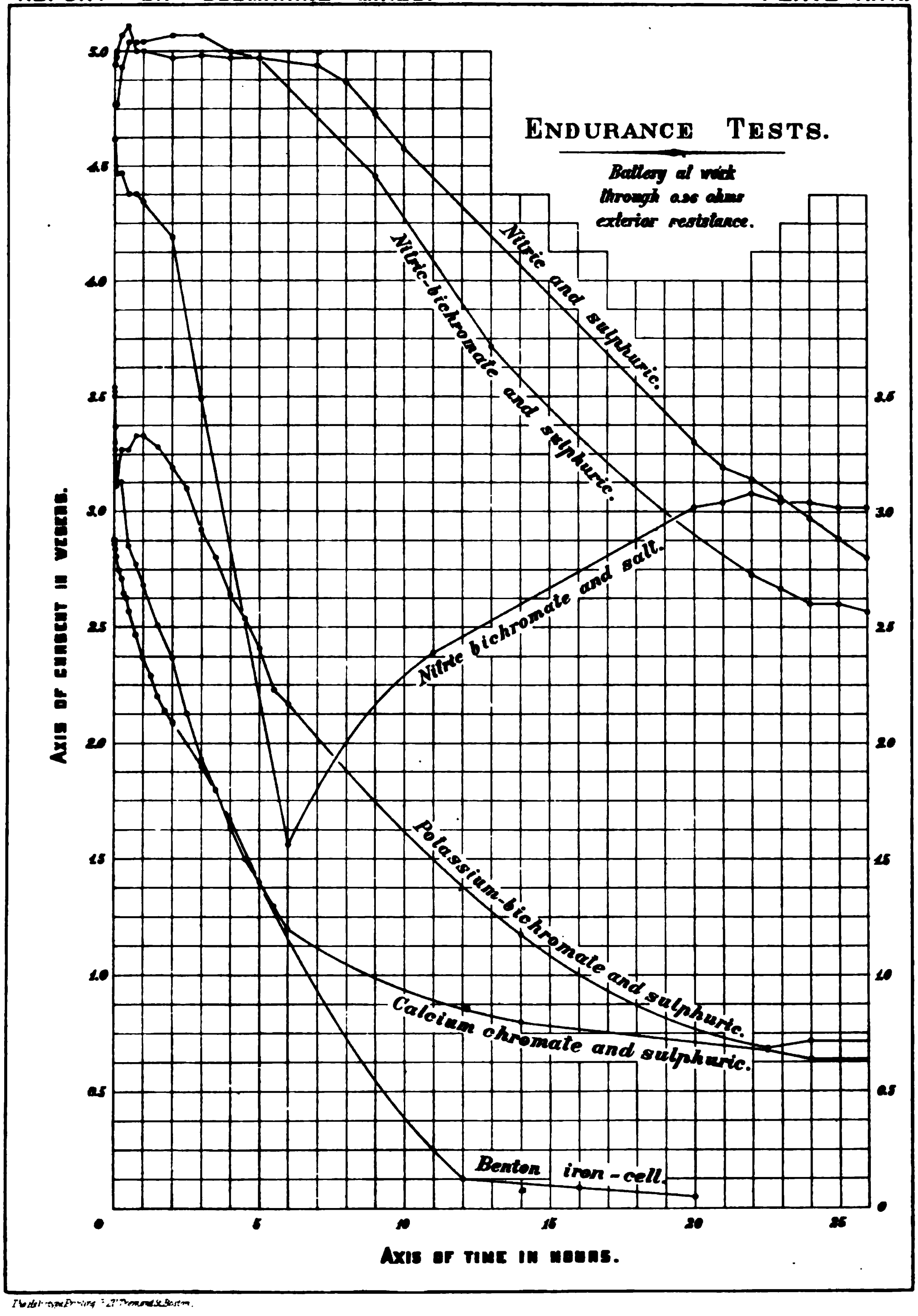
This latter cell was tested for prolonged endurance when working continuously on an exterior resistance of 0.263 ohms, including the galvanometer. Three arrangements were tried—carbon in commercial nitric acid, zinc in $\frac{1}{10}$ sulphuric acid and water; carbon in commercial nitric acid filtered to saturation through crystals of potassium bichromate, with 1 fluid ounce of sulphuric acid added, zinc in $\frac{1}{10}$ sulphuric acid and water; and carbon in the same, zinc in a saturated solution of common salt ($\frac{1}{2}$ pound of salt to 40 fluid ounces of water). The electro-motive force with these solutions before the circuit was closed, was respectively 1.945, 1.980, and 1.970 volts. At the end of the trials this quantity had fallen to 0.13, 0.53, and 0.11 volts respectively, no time being allowed for partial recovery. The following table exhibits the characteristic results of these tests, many intermediate observations being omitted as superfluous. They are also shown to the eye on Plate XXVII:

Endurance of the nitric acid cell—working on 0.263 ohms.

Time at work.		Nitric and sulphuric.			Nitric-bichromate and sulphuric.			Nitric-bichromate and salt.		
		C by galvanometer.	C by condenser.	Remarks.	C by galvanometer.	C by condenser.	Remarks.	C by galvanometer.	C by condenser.	Remarks.
h.	*m.*	*Webers.*	*Webers.*		*Webers.*	*Webers.*		*Webers.*	*Webers.*	
0	1	4.94	5.00	Air and fluid 58° F.	4.77	4.91	Air and fluid 60° F.	4.62	4.63	Sp. gr. 1.11.
0	2	4.94	4.99		4.77	4.91		....	4.63	
0	3	4.97	4.99		4.77	4.89		....	4.63	
0	4	5.00	4.99		4.77	4.89		....	4.59	
0	5	5.00	5.01		4.77	4.89		4.47	4.49	R, = 0.08.
0	15	5.07	5.03		4.93	4.93	R, = 0.04.	4.47	4.43	
0	30	5.11	5.05	R, = 0.09.	5.04	4.96		4.38	4.41	
0	45	5.00	5.04		5.04	4.96		4.38	4.38	
1	00	5.00	5.07		5.04	4.98	R, = 0.04.	4.35	4.36	
2	00	4.97	5.05	Air 58° F.; fluid 68° F.	5.07	5.01		4.19	4.32	
3	00	4.98	....		5.07	5.01	Air 60° F.; fluid 77° F.	3.49	3.62	R, = 0.24.
4	00	4.97	....		5.00	4.99		....	....	
5	00	4.97	....		4.97	4.97	R, = 0.04; air 60° F.; fluid 80° F.	....	....	
6	00	4.81	....	R, = 0.09.	....	....		1.56	....	R, = 0.78.
7	00	4.94	....		....	....		....	....	
8	00	4.87	....	Air 52° F.; fluid 82° F.	....	....		....	....	
9	00	4.73	....	R, = 0.09; air 51° F.; fluid 82° F.; sp. gr. 1.23.	4.46	....	R, = 0.04.	....	....	
10	00	4.58	....		....	....		....	....	
11	00	....	....		....	....	R, = 0.14; air 58° F.; fluid 74° F.	2.30	....	R, = 0.34.
13	00	....	....		3.72	....		....	....	
20	00	3.30	....	Air 47° F.; fluid 57° F.	....	....		3.01	....	
21	00	3.19	....	Sp. gr. 1.31. R, = 0.23; air 53° F.; fluid 59° F.	....	....		3.04	....	
22	00	3.14	....		2.73	2.87	R, = 0.23.	3.08	3.14	R, = 0.24.
23	00	3.06	....		2.67	....		3.04	3.15	
24	00	2.97	3.10		2.60	2.72	R, = 0.26; air 56° F.; fluid 60° F.	3.04	3.17	
25	00	2.88	....		2.60	2.67		3.02	3.17	
26	00	2.80	2.82	R, = 0.26.	2.57	2.66	Sp. gr. 1.36.	3.02	3.21	
27	00	....	....		2.51	...		3.02	3.18	
29	00	....	....		2.51	2.58		....	....	
31	00	....	....		....	....		2.82	....	R, = 0.23.
34	00	2.42	....	R, = 0.29. Depos'n begins.	2.35	....	R, = 0.34.	....	....	
37	00	....	....		2.17	....		....	....	
38	00	....	....		....	....		2.28	....	R, = 0.29.
44	00	1.53	....	R, = 0.49. Much deposit.	....	....		1.29	....	R, = 0.34.
45	00	1.37	....		....	....		1.18	....	
46	00	1.19	....		....	....		0.99	....	
47	00	1.00	....		0.90	0.88	R, = 0.54.	0.80	....	R, = 0.34.
48	00	0.81	0.80	R, = 0.57.	0.79	....		0.62	....	
49	00	0.60	....		0.69	0.69	R, = 0.64.	0.47	....	R, = 0.44.
50	00	0.40	0.40	R, = 0.78.	0.60	0.60	R, = 0.69.	0.34	....	
51	00	....	....		0.51	0.51	Sp. gr. 1.38.	0.27	....	
70	00	0.05	....	R, = 1.74. Sp. gr. 135.	....	....		0.07	....	R, = 1.04. Sp. gr. 1.21.

The following notes contain information respecting these trials, which could not conveniently be tabulated.

The first cell (ordinary Bunsen) did not fume badly until four or five hours after



ENDURANCE TESTS.

Battery at work through 0.36 ohms exterior resistance.

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the circuit was closed. In about twenty-four hours, dark spots began to form on the zinc and the escape of bubbles of oxygen ceased. In about thirty-six hours, the fluid outside the porous cup became clouded and a gray salt began to deposit near the slit in the zinc. This was about 1.5 inches thick when the trial ceased. The heating and gradual cooling of the fluid, and the steady increase of internal resistance, were noteworthy features.

In the second trial (nitric-bichromate and sulphuric), the outer fluid began to discolor in a couple of hours, and fumes were first noted after nine hours of work. A solid deposit appeared on the bottom of the cell in twenty-two hours, and gradually increased until it finally became more than 2 inches thick. The zinc also was coated with crystals of sulphate of zinc.

In the third trial (nitric bichromate and common salt), the fumes did not become annoying until eleven hours after the circuit was closed. The solid on the bottom of the cell began to deposit in about twenty-four hours; and, at the end, was fully 3 inches thick, being packed so closely between the zinc and porous cup as to require force to separate them. A remarkable reduction of current, followed by a gradual increase and succeeding decrease, will be noted in the table.

In actual service, cells will rarely if ever be subjected to so severe a test as in these experiments; and they show conclusively that either the first or second combination will give a strong and constant current for about eight hours, without renewal of the fluids. The third arrangement is not to be recommended.

The Benton Iron Cell—two-fluid.—A battery capable of occasionally supplying a moderately strong current, and which can be left standing without the destructive local action inherent in every form of the nitric acid cell, is sometimes useful; and Colonel Benton has devised the following pattern to meet this end:

The jar is of cast iron, 6½ inches in diameter and 6½ inches deep. The positive plate, also of cast iron and cylindrical in form, exposes 140 square inches to the surrounding fluid, which consists of a saturated solution of sodium chloride (1 pound to 4⅜ pounds of water). The negative plate consists of a carbon slab, 0.8 by 2 by 9 inches long, immersed 7 inches in a porous cup of white earthenware filled with the following mixture: 6 ounces of peroxide of manganese, 6 ounces of broken carbon, 8 ounces of water, 5⅓ ounces of sulphuric acid, and 1½ ounces of a saturated solution of potassium bichromate in nitric acid. The surface of the carbon plate exposed to the fluid is 40 square inches. The internal resistance of this cell, when fresh, is 0.18 ohms; but it rapidly increases after the circuit is closed. The electro motive force is about 1.5 volts.

To determine the relative capacity of this element for hard work, as compared with the nitric acid cell, the following measurements were made. A larger external resistance would more perfectly have tested its merits for the object for which it was devised; but as I desired especially to learn its value for producing the electric light, a low resistance was selected.

Three special tests were made with this cell set up exactly as proposed by Colonel Benton. In the first, the external resistance was 0.23 ohms, or about equal to the internal; and in the second, 1.05 ohms, or about five times this quantity. The third trial was made to test recuperative power; the cell was allowed to work as in the first test for twenty hours, left at rest for forty-eight hours, and then set at work again on the same circuit. The following table exhibits the results of these trials; see also Plate XXVII:

Endurance of the Benton iron cell.

Time at work.	First trial: $R_{,,} = 0.23$ ohms.			Second trial. $R_{,,} = 1.05$ ohms.			Third trial. $R_{,,} = 0.23$ ohms.		
	C by galvanometer.	C by condenser.	Remarks.	C by galvanometer.	C by condenser.	Remarks.	C by galvanometer.	C by condenser.	Remarks.
h. m.	*Webers.*	*Webers.*		*Webers.*	*Webers.*		*Webers.*	*Webers.*	
0 1	2.88	3.20	$E = 1.50$ volts. $R_{,} = 0.18$ ohms.	....	....	$E = 1.41$ volts. $R_{,} = 0.18$ ohms. New cell, but had been at work for 10 minutes on 0.23 ohms.	2.43	2.34	$E = 1.54$ volts. $R_{,} = 0.36$ ohms.
0 2	2.88	2.98		0.93	....		2.43	2.29	
0 3	2.86	2.79		....	....		2.43	2.25	
0 4	2.84	2.78		0.92	0.92		2.41	2.24	
0 5	2.81	2.78		0.91	0.92		....	2.22	
0 10	2.75	2.78		0.89	0.88		....	2.16	$R_{,} = 0.37$ ohms.
0 15	2.71	2.67		0.87	0.86		....	....	
0 20	2.65	2.64		0.84	0.84		....	....	
0 25	2.63	2.62		0.81	0.81		....	....	
0 30	2.57	2.60		0.78	0.79		2.16	2.04	
0 45	2.47	....		0.68	0.71		....	....	
1 00	2.37	....		0.64	0.66		2.05	1.94	
1 15	2.29	....		0.59	....		....	....	
1 30	2.20	....		0.55	....		1.98	1.88	
1 45	2.14	2.19		0.54	0.56		....	....	
2 00	2.09	2.17		0.52	0.54		1.95	1.83	
3 00	1.90	....		0.48	0.50		1.89	1.75	
4 00	1.67	1.74		....	....		1.81	....	
8 00	0.92	....		....	....		1.53	....	$R_{,} = 0.67$ ohms.
12 00	0.13	....		....	....		0.34	....	$R_{,} = 3.77$ ohms.
16 00	0.09	....		....	....		0.13	....	
20 00	0.05	....		....	....		0.08	....	$R_{,} = 9.27$ ohms.
				REST OF TWO DAYS.					
0 1	....	....		....	....		1.56	1.38	$E = 1.39$ volts.
0 2	....	....		....	....		1.58	1.38	
0 3	....	....		....	....		1.57	1.36	
0 4	....	....		....	....		1.54	1.32	
0 5	....	....		....	....		1.48	1.39	$R_{,} = 0.74$ ohms.
0 15	....	....		....	....		1.35	....	
0 20	....	....		....	....		1.15	....	
0 25	....	....		....	....		0.96	....	
0 30	....	....		....	....		0.77	....	
0 45	....	....		....	....		0.48	....	$R_{,} = 2.77$ ohms.
1 00	....	....		....	....		0.30	....	
1 15	....	....		....	....		0.35	....	$R_{,} = 3.47$ ohms. $E = 1.30$ volts.

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On comparing these figures with those on page 298, the immense superiority of the nitric acid cell for really hard work is apparent. The iron cell evidently is only suited for working on a resistance large enough to reduce the current say to a quarter of a weber. On such a circuit, especially if intermittent work only be required, it serves a useful purpose.

The peculiarity of the cell appears to be the rapid increase of internal resistance, which is well illustrated by the third trial reported in the last table. A solid deposit begins to form at the bottom of the jar, and in the pores of the porous cup, shortly after the closing of the circuit; and it appears to increase while the work continues. This is the worst feature of the combination, since it involves frequently washing the porous cup in dilute muriatic acid to prevent the steady increase of internal resistance noted above. When only occasional work is required, this difficulty is less troublesome, as there is an evident tendency to redissolve during intervals of rest.

The Chromic Acid Cell—two-fluid.—The class of voltaic cells included under this and the next heading is large and interesting, being exceptionally well suited to the electrical ignition of fuzes. The chemical reaction is so intense, and the depolarization of the negative plate so perfect, that the electro-motive force for a few seconds rather exceeds that of the nitric acid battery. A low internal resistance is easily secured by a suitable adjustment of the plates.

The marked defects of the combination are the rapid deterioration of the fluid under the action of the current, and the deposition of chrome alum. The advantages, the high electro-motive force and the entire absence of fumes or corrosive vapors.

The acid is usually obtained either from potassium bichromate or from calcium chromate; and a certain per cent. of sulphuric acid is added to prolong the endurance of the fluid Hot water is used as the solvent.

The first series of trials was designed to determine the best proportions of the component parts of the fluid, concerning which different authorities are at variance. After many measurements, the details of which it is not necessary to report, the following formula was adopted as best suited for use in submarine mining:

To 1 gallon of boiling water add 6 pounds of potassium bichromate. After stirring about fifteen minutes, add 4 gallons of cold water and 1 gallon of sulphuric acid of commerce Stir occasionally until all the bichromate crystals are dissolved. This mixture may be procured in the New York market under the name of electropoion fluid.

The proportions used in the trials of the calcium chromate fluid were the same, viz, 6 pounds of the salt dissolved in 5 gallons of water mixed with 1 gallon of sulphuric acid of commerce. Only the clear liquid was placed in the cells. The chief advantage of this solution is the absence of the troublesome chrome alum crystals, deposited upon the negative plate and the cell.

When this form of battery is used on a closed circuit of moderate resistance, a portion of the fluid in the porous cup should be renewed about once in two days and replaced by fresh; and about once a week the whole solution should be renewed. The change of color from a rich red to a dirty blue indicates when the strength of the fluid is exhausted. Thus treated, this element may be usefully employed as a signal battery in submarine mining when many mines are operated upon a closed circuit.

The chromic acid cell does not possess sufficient endurance for the production of the electric light unless two batteries are employed, switched alternately into the circuit The following trials were made in January, 1877, to afford a direct comparison with the experiments upon the nitric acid cell already reported; the same jar, plates, outer fluid, and external resistance being used in each set.

Endurance of the chromic acid cell—working on 0.263 *ohms.*

Time at work.	Potassium bichromate and sulphuric.			Calcium chromate and sulphuric.		
	C by galvanometer.	C by condenser.	Remarks.	C by galvanometer.	C by condenser.	Remarks.
h. m.	*Webers.*	*Webers.*		*Webers.*	*Webers.*	
0 1	3.54	3.61	E = 1.97 volts; R, = 0.14 ohms.	3.52	3.55	E = 1.82 volts; R, = 0.16 ohms.
0 2	3.30	3.34		3.37	3.40	
0 3	3.21	3.27		3.27	3.29	
0 4	3.19	3.20		3.16	3.21	
0 5	3.14	3.20		3.11	3.18	
0 15	3.27	3.26		3.13	3.20	
0 30	3.27	3.33		2.85	2.87	
0 45	3.33	3.35		2.77	2.75	
1 00	3.33	3.35		2.68	2.67	
1 30	3.28	3.24		2.51	2.49	
2 00	3.19	3.15	Air 66° F.; fluid 73° F.	2.37	2.32	
2 30	3.10	....	R, = 0.09 ohms.	2.13	2.15	
3 00	2.92	2.89		1.93	2.05	R, = 0.16 ohms.
3 30	2.80	2.74		1.80	1.89	
4 00	2.64	2.61		1.64	1.71	
4 30	2.54	2.50	R, = 0.09 ohms.	1.50	1.56	
5 00	2.41	2.44	Air 64° F.; fluid 73° F.	1.40	1.46	
5 30	2.23	....		1.30	1.37	R, = 0.16 ohms.
6 00	2.17	....		1.20	....	
14 00	1.18	....	R, = 0.14 ohms.	0.80	....	R, = 0.19 ohms.
22 30	0.69	....	R, = 0.18 ohms.	0.68	....	R, = 0.18 ohms.
24 00	0.72	....	R, = 0.17 ohms.	0.64	....	
30 00	0.71	....	R, = 0.18 ohms.	0.64	....	
47 00	0.64	....	R, = 0.19 ohms.	0.58	....	R, = 0.19 ohms.
53 00	0.61	....		0.58	....	R, = 0.19 ohms.
72 00	0.55	....	R, = 0.19 ohms.	0.49	....	R, = 0.26 ohms.
77 30	0.54	....		0.41	....	
95 00	0.48	....	R, = 0.26 ohms.	0.40	....	R, = 0.34 ohms.
100 00	0.44	....	E = 0.30 volts; R, = 0.27 ohms. No solid deposit.	0.40	....	E = 0.11 volts; R, = 0.78 ohms. No solid deposit.
197 00	....	....		0.07	....	

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By comparing this table with that on page 298, (see also Plate XXVII), the great inferiority in strength of the chromic acid cell to the nitric acid cell is apparent. It will also be noted that they differ, both in the rate of increase of internal resistance and in respect to the solid deposit, possibly because the absolute work, and hence the consumption of zinc, is very different.

It would also appear that for use in a two-fluid cell the calcium chromate solution is slightly inferior in endurance to the potassium bichromate solution.

The Chromic Acid Cell—single fluid.—This battery combination is perhaps the best of any for industrial applications requiring the ignition of low-tension fuzes. It was employed by General Newton at the great blast near Hallett's Point, in 1876; and for smaller operations it is second in convenience only to portable dynamo-electric apparatus.

The action of the bichromate solution (already described) upon zinc is very intense; and the plates, therefore, should be immersed only at the moment of firing. There are many devices for fulfilling this condition, and some of them will soon receive notice; but attention will first be directed to certain experiments designed to measure the rate of deterioration, which is excessively rapid after the closing of the circuit.

Many trials were made with this object in view, but they were all in some degree unsatisfactory, owing to the time required for the settling of the galvanometer needle after the circuit was closed. The time needful to explode fuzes is inappreciable; but the reduction of current is so rapid during measurements, that the thirty seconds or more required for bringing the needle to rest reduces the effective strength of the cell to an extent which can hardly be calculated. This difficulty was overcome in the following manner, thanks to a happy suggestion of Lieut S. S. Leach, Corps of Engineers, when serving with the Battalion of Engineers, in January, 1877.

The glass cover of the galvanometer was removed, and a small rod of sealing-wax was attached to its under side. The length was sufficient to cause it to touch the side of the needle, which could, therefore, be deflected mechanically to any desired reading of the scale. A few trials made it easy with this device to place the needle so as hardly to move when the circuit was closed. A turn of the glass backward then left the latter free to gradually fall as the current weakened. By combining the use of this contrivance with a break circuit chronometer and chronograph, the following measurements were successfully made:

The cell contained, immersed in a large volume of the fluid, a carbon and a zinc plate, each 0.7 inches by 2.7 inches, exposing 3.78 square inches to the solution. The distance between them was 0 2 inches.

The electro-motive force before the circuit was closed was 1.97 volts; and the internal resistance increased from about 0.5 ohms to 1.5 ohms in 30 seconds, the potassium bichromate and the calcium chromate solutions both giving identical values for these quantities, as nearly as could be measured. The external resistance was about 0.1 of an ohm for each set of trials. The fluid was nearly fresh at the first trial, and was renewed at the third trial of the potassium bichromate solution; for the calcium chromate solution, it was fresh at the start and no change was made. The intervals between the trials (during which the circuit was open) were about five minutes.

Endurance of the calcium chromate cell.

SINGLE FLUID.

Galvanometer.		Time after closing the circuit.						Grand mean.
Reading.	Current.	First trial.	Second trial.	Third trial.	Fourth trial.	Fifth trial.	Sixth trial.	
°	*Webers.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*
76	3.32	0.0	0.0	0.0	0.0	0.0	0.0	0.0
75	3.09	0.6	0.7	0.5	0.6	0.6	0.6	0.6
74	2.89	2.8	2.9	0.9	1.1	1.1	1.1	1.6
73	2.71	3.6	3.7	3.6	3.3	3.3	4.5	3.7
72	2.55	6.0	6.2	5.9	5.4	4.7	6.3	5.7
71	2.40	8.9	9.6	8.4	7.0	6.3	8.6	8.1
70	2.27	10.2	14.5	11.5	8.7	8.7	10.1	10.6
69	2.16	11.0	17.4	15.7	12.5	11.2	12.2	13.3
68	2.05	13.6	20.4	18.7	16.4	13.3	15.1	16.2
67	1.95	....	24.6	22.6	19.8	16.2	18.5	20.0
66	1.86	19.0	29.4	26.3	23.3	20.3	22.6	23.5
65	1.78	21.1	34.3	31.9	28.6	23.8	27.5	27.9
64	1.70	24.8	42.5	38.7	34.9	27.7	33.2	33.6
63	1.62	30.2	52.6	48.5	42.3	35.5	39.0	41.3
62	1.56	33.5	59.5	56.6	49.5	42.3	45.3	47.8
61	1.49	38.6	....	....	58.8	49.4	53.4	....
60	1.43	44.5	....	....	....	58.9	60.4	....

Endurance of the potassium bichromate cell.

SINGLE FLUID.

Galvanometer.		Time after closing the circuit.						Grand mean.
Reading.	Current.	First trial.	Second trial.	Third trial.	Fourth trial.	Fifth trial.	Sixth trial.	
°	*Webers.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*	*Sec.*
76	3.32	0.0	0.0	0.0	0.0	0.0	0.0	0.0
75	3.09	....	2.4	1.1	0.6	1.0	0.6	1.1
74	2.89	....	3.2	1.6	0.9	1.4	1.2	1.7
73	2.71	....	4.5	2.9	3.3	3.7	3.0	3.5
72	2.55	8.9	6.3	4.0	4.4	5.6	3.2	5.4
71	2.40	13.9	8.7	5.6	5.4	7.0	3.8	7.4
70	2.27	16.9	9.5	7.8	10.5	8.9	4.7	9.7
69	2.16	21.6	11.7	9.1	12.6	10.6	6.0	11.9
68	2.05	25.8	12.7	13.4	14.7	11.8	6.2	14.1
67	1.95	30.3	15.2	16.0	16.6	14.2	7.0	16.4
66	1.86	34.4	18.4	17.7	19.6	15.5	8.8	19.1
65	1.78	39.3	22.0	19.9	21.0	17.8	9.7	21.6
64	1.70	42.8	27.8	23.1	23.6	20.2	12.4	25.0
63	1.62	47.8	34.9	26.4	27.0	22.8	14.0	28.8
62	1.56	55.0	....	30.4	30.9	27.1	16.4	34.4
61	1.49	60.4	58.6	36.5	35.1	31.5	20.2	....
60	1.43	....	....	43.0	40.4	35.4	25.3	....

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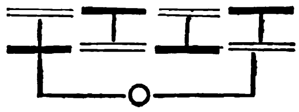
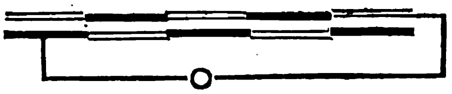
A comparison of these tables indicates that at first the two solutions are practically equal in strength, but the calcium chromate seems to exhibit more endurance. The figures also give a striking proof of the rapid polarization caused by continuous action. In thirty seconds one-half of the original strength of current is lost! For firing fuzes, however, this is a matter of little importance; since the work is done in a small fraction of a second after the circuit is closed.

The next trials to be reported were designed to secure data for devising a form of this battery suited for use in a self-acting mine. The shock of the vessel striking the torpedo is made to immerse the plates in the fluid; but as the blow may take effect in any horizontal direction, it is not easy to employ cells in which the fluid is entirely separate. The problem, therefore, in general terms, was to determine to what extent use might be made of the fluid resistance to increase the electro-motive force of several sets of plates plunged in a single fluid receptacle.

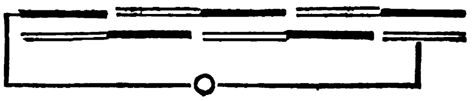
Several different arrangements were tried, the plates being of platinum foil and zinc, each 1.5 inches long and 0.5 inches wide, and wholly submerged in the potassium bichromate solution already described.



I. When eight of these plates were coupled by connecting wires (platinum to zinc) in separate sets of two, about one-fourth of an inch apart, and were hung over an ebonite rod, thus forming four sets of plates in the same cell placed *edge to edge* and alternately zinc and platinum, leading wires from one terminal zinc to the other terminal platinum failed to carry enough current to fire a service low-tension fuze in the circuit; *i. e.*, the current was less than half a weber.



II. A like result followed, as was expected, when five alternate zinc and platinum plates were soldered at their vertical edges, and were placed, zinc opposite platinum, one-fourth of an inch from a similar compound plate.



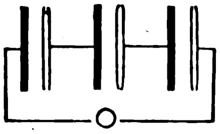
III. This plan was precisely like the second, only the first compound plate was separated into three parts at the first and third junctions, and the opposed compound plate at the second and fourth junctions, making two single and four compound plates, all plunged in a single cell. The fuze could be exploded with 1.6 ohms unplugged in the circuit. The electro-motive force of this combination, as determined by Law's method, was 2.1 volts, showing a gain in potential over two single plates in the ratio of 2.10 to 1.97, or, say, one-eleventh.

IV. This plan was like the last, only the plates were stuck to glass by marine glue instead of being suspended so as to expose both surfaces to the fluid, thus reducing the surface one-half. The fuze could be fired with 0.6 ohms unplugged in the circuit, showing a decided loss as compared with the last plan. The electro-motive force of this combination was 2.1 volts, and the internal resistance was 2.6 ohms. Hence:

$$C=\frac{2.1}{2.6+0.8+0.3+0.6}=0.49\text{ webers};$$

which confirms the accuracy of the measurements, since this strength of current is required to explode the fuze.

V. The next trial was designed to determine the effective value of two single plates, each exposing a surface equal to that of three of the small plates used in the other experiments—the distance between them being a quarter of an inch. The fuze exploded with 1.2 ohms unplugged; or through a total resistance of $R_{,}+0.8+0.3+1.2=R_{,}+2.3$ ohms. The internal resistance was 1.7 ohms, and the electro-motive force 1.97 volts.



VI. The plates were next united by wires, zinc to platinum as in the first trial, and were suspended by the ebonite rod so as to oppose their *sides* to each other. The plates united by wires were one inch apart, and the different sets were one-fourth of an inch apart. Single plates, one of zinc and one of platinum, were placed at the ends, each opposed to and one-fourth of an inch from one of the other metal of the coupled plates. This arrangement, therefore, was precisely like ordinary cells coupled in series with the plates one-fourth of an inch apart, but they were all plunged in the same fluid. With five pairs of plates (four united by wires and the others forming the separate terminals) the fuze could be fired with 1.6 ohms unplugged; with three pairs of plates the same result was obtained through 1.4 ohms; with two pairs of plates, through 1.2 ohms; and with one pair of plates, through 0.8 ohms. The resistance of the fuze being 0.8 ohms, and of the leading wires 0.3 ohms, the total resistance in these three circuits, respectively, was $R_{,}+2.7$, $R_{,}+2.5$, $R_{,}+2.3$, and $R_{,}+1.9$ ohms. The internal resistance with three pairs of plates was 4.5 ohms. These figures show a small but rapidly decreasing gain from increasing the number of pairs of plates.

VII. This arrangement was precisely like the last, only the opposed plates were in different vessels, making ordinary separate cells. By three such cells a fuze could be fired with 4 ohms unplugged in the circuit, or through $R_{,}+0.8+0.3+4.0=R_{,}+5.1$ ohms. The internal resistance of each cell was 2.0 ohms. Hence, denoting the effective electro-motive force of three pairs of plates in the sixth arrangement by $E_{,}$ and in the seventh arrangement by $E_{,,}$:

$$\frac{E_{,}}{E_{,,}}=\frac{4.5+2.5}{3\times2+5.1}=0.6$$

Hence the gain in electro-motive force resulting from using three sets of plates arranged in series in a single cell, over two single plates, was as 0.6×6 to 2; or as 1.8 to 1.

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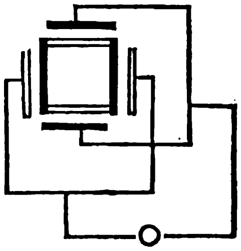
In fine, the conclusion was reached that a subdivision into separate cells to be filled from a common receptacle, was the preferable mode of arranging a battery for the object in view; but that some intercommunication through the fluid would not be fatal to the efficacy of the cell, if properly arranged.

Acting upon this opinion, four sets of these plates were arranged in a circular ring of ebonite, separated by vulcanized rubber diaphragms, the supply of fluid coming through a central hole from a reservoir below. The connections were made as shown in the diagram, the object being to secure effective action whether two, three, or four adjacent cells were filled by the fluid—in the latter case even if all of the plates were plunged into such an excess of fluid as to make intercommunication throughout the whole. Experiment proved that the fuze exploded when two adjacent cells were filled, with 1.6 ohms unplugged in the circuit; when three adjacent cells were filled, with 1.1 ohms unplugged; and with four surcharged cells when 1.0 ohm was unplugged. Negative plates of platinized silver gave apparently identical measurements.



This result was deemed satisfactory, and a battery has been arranged upon these principles, compact and simple in its connections, which will fire the fuze through 2 ohms unplugged in the circuit, in addition to its own resistance. The details of this arrangement are not made public.

An account will now be given of other forms of the single fluid chromic acid cell, which have been tested at Willets Point for use in military and industrial ignitions of low-tension fuzes

Early in 1872, a form of this battery was perfected for trial as a firing battery in submarine mining. It was composed of fifty cells coupled in series. The plates consisted of carbon and zinc, to be immersed in insulated lead cells when required for use. Each plate was 9 inches by 4.5 inches—submerging 6.5 inches by 4.5 inches. They were placed half an inch apart. The cells were 9 by 6 by 1.5 inches, arranged in five boxes of ten cells each. The total floor space occupied by these boxes and the tripping apparatus was 11 by 6 feet. All the plates were rigidly attached to a frame supported over the cells by a counterpoised walking beam, operated upon a system similar to that employed for ringing fire alarms in New York City. A small local battery, by the aid of an electro-magnet, plunged the plates in the fluid and again raised them, either automatically when a torpedo was struck by the enemy or at the will of the operator.

The internal resistance of this battery was about 0.2 ohms per cell, and its electromotive force about 2 volts, giving the formula:

$$C = \frac{2 \times 50}{0.2 \times 50 + R_{\prime\prime}} = \frac{100}{10 + R_{\prime\prime}} \text{ webers.}$$

Hence a single service fuze could be fired in a circuit of about 190 ohms, or at a distance of say 15 miles; for two or more service fuzes coupled in series, these numbers would be 56 ohms and 4 miles, respectively.

This battery was set up, and occasionally used, for two years and a quarter. The room was not heated, but no freezing was noted. Finally, the hard deposit of chrome alum within the cells and upon the carbons caused the breaking of two or three of the latter when they were plunged in the fluid.

This accident would not have occurred with the care which would be given to a firing battery in service; but the mechanism was objectionable on the ground of want of simplicity, and, a better element having been found, the chromic acid cell was finally rejected for this use.

While experimenting with voltaic induction apparatus, for igniting the mines at will, it became needful to select a suitable battery. None appeared to be so well adapted to all the requirements as the chromic acid cell, and the pattern known as the Grenet proved serviceable. Two cells coupled in series gave the requisite current. This pattern consists of a glass bottle enlarged to a globe below, and containing two long carbons kept permanently in the fluid; they are both connected to a single terminal on the ebonite cover. The zinc plate slides up and down between them, so that it may be inserted at pleasure in the fluid. The submerged surfaces of the plates are about 3 by 2 inches, giving a total opposed zinc surface of about 12 square inches. The internal resistance when the fluid is fresh is a small fraction of an ohm.

A couple of these cells were kept set up and frequently used for about two years, the fluid and zinc being occasionally renewed as required. They ultimately became unserviceable by reason of the creeping up of the salts on the carbon plates. The connections under the cover were thus attacked and destroyed; but they were easily renewed by one of our soldiers.

A battery devised by Dr. John Byrne, of Brooklyn, is admirably suited for this kind of work. His object was to replace the cumbersome forms in general use for surgical cautery, by a pattern as compact and powerful as could be made; and he has succeeded in surpassing in these respects all other known combinations. This success was not the result of chance, but was worked out by a happy combination of theory and experiment.

His cell has deservedly excited much attention among electricians in Europe. It was exhibited in London before the Society of Telegraphic Engineers, on February 27, 1878, where it gave rise to an interesting discussion which will be found reported in Vol. VII of their Journal. A paper upon the battery, which was subsequently read by Mr. W. H. Preece before the Physical Society, was printed in the same volume among the Abstracts and Extracts.

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On April 14, 1875, Dr. Byrne brought three early patterns of his battery to Willets Point for experiment, and the following results were then reached:

The earliest form consisted of two cells coupled in series. Each cell contained eight zinc and eight coke plates, each set united to a single conducting wire. The small plates all exposed 4 by $1\frac{1}{4}$ inches, or 10 square inches, to the fluid. They were placed in a double row about $\frac{3}{16}$ inches apart, zinc and coke alternating in both directions. The whole cell thus contained 70 square inches of zinc opposed to a like surface of coke. An arrangement was added by which air could be forced laterally through the cell when in action.

When these cells, charged with the potassium bichromate solution, were put at work through a Gaugain galvanometer of which the weber coefficient was accurately known, the following results were obtained:

	Webers.
Fluid at rest; current through 0.09 ohms of external resistance	23.74
Air forced through fluid; through 0.09 ohms of external resistance	22.13
Fluid at rest; current through 10.09 ohms of external resistance	0.36
Air forced through fluid; current through 10.09 ohms of external resistance	0.36

Applying Ohm's formula to these figures, it appears that if the electro-motive force of one of the cells be 2 volts, its internal resistance is about 0.04 ohms, giving more correctly for the last two measurements 0.39 webers.

Another of the three forms tested on April 14, 1875, was known as the double cell. It consisted of two separate rows of plates, coupled in series in a single compartment charged with potassium bichromate. Each row contained three zinc plates coupled as one, and two copper plates covered with platinum foil and alternating with them, also coupled as one. Each row thus exposed 16 square inches of positive plate opposed to a like surface of negative plate, giving for the whole double cell 32 square inches of active surface. The current of air, which forms a distinctive feature of all of Dr. Byrne's batteries, was introduced laterally.

The first object was to determine the effective electro-motive force of this peculiar combination. Tested by Law's method before closing the circuit, one row indicated 1.99 volts; and both rows united, 2.76 volts, showing a falling off, in the ratio of 1.44 to 1.00, below what would have been obtained had two separate compartments been employed. A measurement of the strength of current by the Gaugain galvanometer then gave the following result:

	Webers.
Fluid at rest; current through 0.09 ohms of external resistance	8.99
Air forced through fluid; current through 0.09 ohms of external resistance	15.00
Fluid at rest; current through 10.09 ohms of external resistance	0.28
Air forced through fluid; current through 10.09 ohms of external resistance	0.28

Assuming, what our experiments with a heated wire abundantly verified, that the current of air maintains the electro-motive force at its original value, Ohm's formula applied to these figures indicates 0.09 ohms as the internal resistance of this double cell, giving more correctly for the last two measurements 0.27 webers.

The third and most recent pattern tested on this date, consisted of a four cell battery. Each cell, charged with potassium bichromate, contained 16 square inches of zinc surface opposed to a like surface of the compound copper and platinum foil negative. The air was forced upward under the plates. Several trials were made, and in the order reported:

WITH FOUR CELLS COUPLED IN SERIES.

	Webers.
Fluid at rest; current through 0.09 ohms of external resistance	5.05
Air forced through fluid; current through 0.09 ohms of external resistance	9.53
Fluid at rest; current through 10.09 ohms of external resistance	0.56
Air forced through fluid; current through 10.09 ohms of external resistance	0.56

WITH FOUR CELLS, TWO IN SERIES AND TWO IN MULTIPLE ARC.

Fluid at rest; current through 0.09 ohms of external resistance	12.63
Air forced through fluid; current through 0.09 ohms of external resistance	19.02
Fluid at rest; current through 10.09 ohms of external resistance	0.31
Air forced through fluid; current through 10.09 ohms of external resistance	0.31

Measurements were next made through the usual cautery circuit and the Gaugain galvanometer. The former had a resistance when cold of about 0.12 ohms, which included 8.5 inches of No. 21 platinum wire. Adding my leading wires (0.09 ohms) gave 0.21 ohms (cold) for the actual external resistance.

WITH FOUR CELLS, TWO IN SERIES AND TWO IN MULTIPLE ARC.

	Webers.
Fluid at rest; circuit as just stated	8.97
Air forced through fluid; circuit as just stated	10.51

The platinum wire was not reddened, but was heated sufficiently to carbonize paper.

WITH FOUR CELLS COUPLED IN SERIES.

	Webers.
Fluid at rest; circuit as just stated	8.97
Air forced through fluid; circuit as just stated	14.33

This brought the platinum wire to a bright red heat.

The same fluid was used in all these trials, and at the end its temperature had risen more than 60° Fahr. With fresh fluid and the four cells coupled in series, 5.5 inches of No. 16 platinum wire were brought to a white heat and kept steadily at that temperature for several minutes.

Since the external circuit was not sensibly heated in the first two sets of observations with this pattern of the battery, they admit of analysis by Ohm's formula in the manner already indicated The first gives for the internal resistance 0.19 ohms; and the second, 0.12 ohms—the temperature of the fluid being considerably higher at the latter measurement.

On April 8, 1876, Dr. Byrne brought the perfected pattern of his battery to Willets Point for experiment. It consisted of four cells, each containing about 7.5 ounces of the bichromate solution. A single zinc plate was placed between two of his special negative plates—20 square inches of zinc surface being opposed to an equal surface of the latter, at distances of about $\frac{3}{16}$ of an inch. Each negative con-

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sisted of "a plate of copper, to one surface of which, as well as to its edges, a sheet of platinum foil compact and free from holes, is soldered, and to the opposite surface or back, a sheet of lead—the three metals being so united that the copper shall be effectually protected from the action of acid. The lead back and edges are then coated with asphaltum varnish, acid proof cement, or any other like substance; and lastly, the platinum face being first rubbed over gently with emery paper is to be thoroughly platinized in the usual manner." The current of air was introduced under the plates through rubber tubes, by a pneumatic agitator worked by hand or by the foot.

The internal resistance of a single cell when the air was traversing it was first measured by Mance's method, using a delicate bridge specially prepared for the purpose. Repeated trials gave the following results, the temperature of the fluid (fresh) rising from 60° Fahr. during the process:

	Ohms.
First set; fluid 118° Fahr.; internal resistance	0.064
Second set; fluid 79° Fahr.; internal resistance	0.082
Third set; fluid 98° Fahr.; internal resistance	0.093
Mean,	0.080

The electro-motive force was then measured by Law's method and a standard Clark cell, without closing the circuit—a method which may be accepted as giving a true gauge for the battery in action with air traversing the fluid, since a platinum wire instantly heated to redness suffers no change of color for several minutes.

	Volts.
First set; same fluid, 98° Fahr.; electro-motive force	2.06
Second set; fresh fluid, 60° Fahr.; electro-motive force	2.05
Third set; fresh fluid, 84° Fahr.; electro-motive force	2.08
Fourth set; calcium chromate, 78° Fahr.; electro-motive force	2.04
Mean,	2.06

In fine, it would appear from the foregoing trials that, when the temperature of the fluid is high, the maximum action of Dr. Byrne's perfected battery may be represented by the following formula, in which n denotes the number of cells coupled in series. It is applicable either to the potassium bichromate or to the calcium chromate solution. The latter is decidedly preferable, because as already seen the action is more enduring, and hence the maximum strength of current may be longer maintained—an inference confirmed by Dr. Byrne's experience.

$$C = \frac{2.06\,n}{0.06\,n + R_{,,}}$$

These trials throw light upon the vexed question as to the secret of the extraordinary power of this battery. It will be noted that the current of air forced through the cell, increases the current only when the resistance of the exterior circuit is so small as to develop a strong chemical action; *i. e.*, under conditions when the chromic acid cell loses power very rapidly by polarization (see table on page 304).

By polarization is understood the effects of a coating of hydrogen upon the negative plate and of oxygen upon the positive plate, produced by intense action. These coatings act injuriously in two distinct modes. First, by setting up an opposing electro-motive force they cut down the normal value of that quantity; second, by covering a part of the plates they virtually reduce the surface exposed to the fluid, and hence increase the internal resistance. Now, the current of air mechanically removes these coatings, and also keeps fresh fluid always in contact with the zinc. The intense action and the consequent rapid consumption of that metal raise the temperature of the fluid, and thus, by making it more conducting, reduce the internal resistance and tend to offset the deterioration of the solution.

The foregoing formula sufficiently explains the rest of the phenomenon. The electro-motive force is exceedingly high and the internal resistance is exceedingly low. The latter is due to the construction of the negative plate, which, by eliminating the defective connections and poor conductivity of the carbon plate, adds enormously to the current when the exterior resistance is nearly zero. This point has been so plainly illustrated when discussing the subject of simultaneous ignitions in the last chapter, that it requires no further notice here.

The ordinary chromic acid single fluid cell is much employed in blasting, being compact, powerful, and easily manipulated. Various patterns are in use, the following being well suited for general work. A strong box is arranged to hold, side by side, from six to ten insulated lead cells, the number varying according to the length of the leading wires and number of simultaneous ignitions. These cells are rectangular in cross-section, about 6 inches deep, 6 inches long, and 2 inches wide. The ends of the box rise to a sufficient height to support above the fluid a frame carrying the plates (carbon and zinc) which should be 6 inches long and 4.5 wide. They are attached rigidly half an inch apart, each pair being over its own cell. The frame is hung by two cords wound round a longitudinal iron rod which admits of easy revolution by a crank. By a toothed wheel and pawl, the plates may be held at any desired position above or in the fluid. If each plate be submerged 4½ inches, the internal resistance per cell is about 0 15 ohms, and the electro-motive force may be assumed as 1.95 volts, giving for fuze firing the working formula:

$$C = \frac{1.95n}{0.15n + R_{\prime\prime}}$$

This formula is based upon very careful measurements, of which the following, made with a 9-cell battery of precisely the dimensions given above, are an example:

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Endurance of potassium bichromate blasting battery.

Time after lowering plates.		External resistance $R_{,}$	E by condenser.		Strength of current.		Remarks.
			9 cells.	1 cell.	By Gaugain.	$\frac{E_{,}}{R_{,,}}$	
h.	*m.*	*Ohms.*	*Volts.*	*Volts.*	*Webers.*	*Webers.*	
0	0	∞	18.27	2.03	....	....	To show rate of polarization due local action on open circuit.
	1	∞	18.06	2.01	....	....	
	2	∞	18.06	2.01	....	....	
	12	∞	17.86	1.98	....	....	
	13	∞	17.86	1.98	....	....	
	15	1.81	17.64	1.96	6.14	5.77	Internal resistance, measured by cell, ranges from 0.10 ohms to 0.23 ohms—mean 0.14 ohms. Whole battery after working 10 minutes gives 0.12 ohms per cell.
	16	1.81	17.64	1.96	5.91	5.77	
	17	1.81	16.79	1.86	5.73	5.50	
	18	1.81	16.10	1.79	5.57	5.27	
	19	1.81	16.10	1.79	5.33	5.27	
	20	1.81	15.58	1.73	5.25	5.10	

Experiments showing the effective work of this battery in exploding fuzes have already been reported on page 248. Larger plates are sometimes used for this purpose, but with no advantage commensurate with the increased weight and cost.

For transportation, the fluid is removed and the plates are lowered into the empty cells, the whole thus forming a compact and convenient battery little liable to injury.

A modification of this arrangement was devised in February, 1872, for boat use in the torpedo experiments at Willets Point, where rough water is often to be expected.

Six cells were prepared with plates fixed in position in one subdivided compartment, the fluid being contained in a lead chamber below them. The whole box was closed, with the terminals and a firing key outside. By revolving this box on its trunnions the battery was ready for use. Its working formula was about the same as that just given.

A neat and very compact three-cell battery of a similar kind was procured at a later date from Ruhmkorff. It consists of a closed ebonite case, 9 by 5 by 2 inches, which may be carried hanging round the neck. The carbons are square rods, 0.4 by 0.4 by 3 inches, surrounded by small cylinders of zinc, the whole attached to the cover and entering ebonite cells. By inverting the case the fluid flows in from a lower receptacle; and one of our service low-tension fuzes may thus be fired through about 4 ohms resistance. The cover carrying the plates is easily removed, for cleaning and renewing the fluid.

The Dilute Sulphuric Acid Cell—single fluid.—This cell, of which the Smee is the original type, has been carefully studied, because under the respective names of von Ebner and Walker it at one time was adopted by Austria and by Great Britain, as the best type of firing battery for submarine mining.

In both these batteries, and in the form prepared for trial in our own service as well, the zinc plate rests permanently in a small cup of mercury, the object being to

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preserve the amalgamation and thus, so far as possible, to prevent local action. The negative plate is of carbon, usually coke in this country and graphite in Europe. The proportion of acid for a firing battery should never exceed about one-twelfth; for electro-plating, one-eighth is usually employed.

All varieties of this cell have one common fault, a low electro-motive force of only about 1.2 volts even when the circuit is first closed; and this soon falls 50 per cent. when at work on a small resistance. The cell has the merits of simplicity, of yielding a very steady current when polarization has reached its limit, and when properly set up of preserving its efficiency without attention for long periods of time.

Considerable diversity exists in the arrangement of the plates. Walker uses two graphite plates with a single zinc between them, copying Wollaston, who bent his copper plate under the zinc so as to effect the same object. Von Ebner uses two zincs with a graphite plate between them. Experience and careful measurement, at the Torpedo School, have shown that these duplications are only useful when the battery is needed for work on short circuit. For a firing battery, single plates of zinc and coke of moderate size fulfil every requirement, and are more easy to keep in order.

After thorough trial, the form of the sulphuric acid battery described below has been found to be effective; and, in case of need, it may always be rapidly prepared. It is decidedly superior to the Walker battery formerly adopted, but now abandoned, by the Royal Engineers.

The jars are of glass, holding about two and a half quarts of the fluid, which consists of dilute sulphuric acid, one part to fourteen by volume. The tops of the jars for about 2 inches are smeared with paraffine oil, to prevent the creeping up of the zinc sulphate.

The zinc plates are 4.5 by 9.5 inches, giving a submerged opposed surface of about 30 square inches. Two inches at top are painted with asphaltum varnish.

The coke plates are 5 by 9 inches, giving a submerged opposed surface of about 30 square inches. The connection is made by two silver wires, sewed through the coke and attached to a small copper bar. The top, for about 3 inches, is soaked in melted paraffine to close the pores, and thus prevent the creeping up of the fluid and consequent deposit of zinc sulphate. The connections, including the copper bars, are painted with asphaltum varnish.

These electrodes are attached together by two small rods of ebonite, which pass through holes made for the purpose, with half inch ebonite washers interposed between the plates to secure uniformity of distance The rods are secured by small washers screwed upon their outer ends, which thus clamp the plates together. Both rods are below the fluid, one near the top and the other near the bottom of the submerged parts of the plates. The zinc plates stand in small cups of gutta-percha containing mercury, to preserve the amalgamation. The cokes being shorter than the zincs do not interfere with these cups.

The cells are coupled by stout copper wires, screwed into the copper bars of the cokes, and held to the copper terminals of the zincs by screw cups.

The cells are placed on paraffined strips of dry wood nailed upon shelves; a method which secures the insulation necessary for a battery of high potential. Curtains prevent dust from settling into the jars.

It has been found by experience that a battery of this kind does not require renewal oftener than once in a couple of years, if care be taken to supply water lost by evaporation, and to occasionally remove any zinc sulphate making its appearance.

A firing battery for coast defence should consist of not less than 100 such cells, which may safely be considered effective at a range of one and a half miles. The electro-motive force per cell before the circuit is closed, is about 1.2 volts; but, owing to rapid polarization, only 1.0 volts should be used in computing the power to fire fuzes. The internal resistance is about 0.3 ohms. Thus the working formula becomes:

$$C = \frac{100}{30 + R_{\prime\prime}}$$

The local battery required with my torpedo system of 1872 belongs to this type. It consists of 10 cells, arranged in a convenient box, which should be open to avoid deposit of moisture from evaporation. The solution, and the preparation of the zincs and cokes, is the same as with the firing battery; but smaller plates, giving opposed surfaces of say 20 square inches, may be used; and the battery does not require to be insulated. The plates are not self-supported, but hang from a cross-bar arranged for the purpose, care being taken to keep the zincs in the mercury.

These patterns were not selected without careful trial. Twenty cells of the Walker battery were tested early in 1872 and found to be defective in insulation, owing to the deposit of moisture caused by the closeness of the boxes in which they were contained. This bad fault was corrected in our service pattern by the simplicity of the connections. The alternative fault, rapid evaporation caused by exposing so large a surface of fluid to the air, was prevented by a thin film of paraffine oil allowed to float on top.

After various preliminary trials, a firing battery consisting of 50 cells of this pattern was set up in May, 1872. In the following March it was increased to 100 cells, and was kept standing and in frequent use until January, 1878. During this long period the cells were charged with fresh fluid four times, and defective zincs were occasionally re amalgamated and sometimes replaced. Constant attention was required to remove zinc sulphate from the jars and connections, and the low electro-motive force was, of course, objectionable. Measurements were frequently made to determine the variations in that quantity and in the resistance; but as a better element was finally adopted it is not necessary to give the details here. Suffice it to say that in an emergency the arrangement would be found entirely serviceable, and to be fairly represented by the formula given above. One hundred cells would require about 30 buckets of water and 725 fluid ounces of sulphuric acid of commerce.

For comparison with this firing battery, 50 cells of another pattern were tested The arrangement was identical except in the negative plates, which were sheets of Beardslee's chrome lead equal in size to the cokes. When first set up, the electromotive force was about 0.2 volts less per cell than with the cokes; and after standing a short time, and especially after working a few seconds, this difference was increased. The internal resistance was about 0.1 of an ohm per cell less with the Beardslee plates, owing to their superior conductivity and better connections; but, upon the whole, the coke negative is decidedly to be preferred because it remains serviceable much longer. The chrome lead negative is subject to one curious action. The weaker cells in the series often become depositing, and the negative plate is soon coated with metallic zinc—thus greatly reducing the effective electro-motive force of the battery.

Notwithstanding its failure in a firing battery of many cells having the plates constantly immersed in the fluid, the Beardslee negative is not without merit for certain purposes. It is composed of sheet lead coated with pulverized metallic chromium, by being passed between rollers. The sharp angular nature of the chromium powder causes it to remain on the lead surface, and thus to afford mechanically a ready escape to the hydrogen when produced in large quantities by intense action. This feature gives great constancy; while the small internal resistance allows immense strength of current on circuits of low resistance.

The pattern known as Beardslee's "gridiron" cell possesses these merits in a high degree, and forms a convenient addition to a physical laboratory. It has been much used at Willets Point for determining the weber coefficients of galvanometers to be stored for actual service, for working small induction coils, and for other work in which a strong and constant current is required. The battery contains six large cells, so arranged that the plates may readily be raised out of the fluid when not in use. Each cell contains two stout zincs cast in the form of gridirons, with the bars vertical. Between them, and in close proximity, is placed the negative plate; which is made of two flat sheets of chrome lead, close together, with strips soldered on the faces in such a manner as to project between the bars of the zinc plates. By this arrangement a surface of 105 square inches of chrome lead is opposed to a like surface of zinc, at a distance not exceeding one-fourth of an inch. In a mixture of one part of sulphuric acid of commerce and seven parts of water, such a cell has an internal resistance of about 0.015 ohms; and, when new, the battery (6 cells) will raise 3 inches of No. 10 iron telegraph wire to a white heat.

The effective electro-motive force per cell varies from 1.1 volts to 0.6 volts, according to the external resistance; and one of the marked peculiarities of the battery is the short interval of time requisite for this quantity to assume a constant value. In a few seconds polarization is complete, so that a galvanometer needle will stand indefinitely at the point at which it first settles, the tendency being rather to increase the deflection as the temperature of the fluid rises under the action of the current. After long use the negative plates deteriorate—probably by the mechanical removal of the particles of metallic chromium under the action of the torrents of hydrogen gas which stream from their surfaces. The peculiar form of the zinc plates adds to the effective strength of current, by promoting a free circulation of the fluid. This was shown by careful comparative trials, the internal resistance of two flat plates of zinc and chrome lead exposing surfaces to the fluid equal to Beardslee's gridiron arrangement, being found to be 0.020 ohms instead of 0.015 ohms, the distance apart being the same.

Before passing to another form of battery, certain experiments, made in the spring of 1873, to determine the relative merit of different negative plates in dilute sulphuric acid, will be reported.

Tests of negative plates in dilute sulphuric acid.

Time after closing circuit.	Platinum foil (polished).	Coke.	Platinized coke.	Chrome iron.	Chrome lead.	Platinized silver.
m. *sec.*	*Webers.*	*Webers.*	*Webers.*	*Webers.*	*Webers.*	*Webers.*
0 30	0.39	0.84	2.85	2.80	2.63	3.34
1 00	0.31	0.64	2.75	2.79	2.64	3.30
1 30	0.29	0.54	2.72	2.77	2.69	3.30
2 00	0.27	0.49	2.65	2.77	2.74	3.28
2 30	0.24	0.44	2.61	2.77	2.79	3.28
3 00	0.24	0.41	2.58	2.77	2.85	3.26
3 30	0.23	0.39	2.57	2.77	2.87	3.24
4 00	0.22	0.38	2.57	2.77	2.89	3.23
4 30	0.22	0.37	2.55	2.77	2.92	3.23
5 00	0.22	0.36	2.54	2.80	2.94	3.21
6 00	0.21	0.34	2.52	2.85	2.95	3.15
7 00	0.20	0.34	2.48	2.84	2.97	3.12
8 00	0.18	0.33	2.48	2.84	2.99	3.06
9 00	0.18	0.33	2.45	2.84	2.97	3.06
10 00	0.17	0.32	2.44	2.84	2.97	3.06
11 00	0.17	0.32	2.44	2.85	2.97	3.06
12 00	0.16	0.31	2.44	2.85	2.95	3.06
13 00	0.16	0.31	2.44	2.85	2.95	3.12
14 00	0.15	0.31	2.44	2.87	2.92	3.17
15 00	0.15	0.31	2.44	2.90	2.92	3.15

These plates were all of equal size and were submerged in the fluid (one part of acid and seven of water) at a distance of one-fourth of an inch from a plate of amalgamated zinc exposing a surface equal to their own, viz, 3 inches long by $\frac{7}{8}$ inches wide, giving 2.6 square inches directly opposed. The jar contained $2\frac{1}{2}$ quarts of fluid. The strength of current sent through an exterior circuit of 0.09 ohms, including a Gaugain galvanometer, was noted. The negative plates were quite new, and consisted of: (1) polished platinum foil; (2) coke made by Chester, of New York;

(3) the same platinized; (4) chrome iron made by Beardslee; (5) chrome lead made by Beardslee; (6) platinized silver foil. The foregoing table exhibits the current generated under these conditions, which afford a severe test of relative depolarizing power.

The great advantage of platinizing the negative plate in this form of battery is apparent from these figures, and the possible merit of chromium also, if plates can be economically prepared in a permanent shape, which has not yet been accomplished.

The Sal-Ammoniac Cell—single fluid.—In all the cells heretofore considered, the current has been generated by the consumption of the zinc by an acid; and when the plates remain in the fluid ready for action, the normal condition of a firing battery suitable for submarine mining, they are all subject to one common difficulty. No matter how carefully the zincs be amalgamated, some local action takes place. This not only wastes the metal, but also causes the continuous formation of salts, which, aided by evaporation, work their way up the plates and open a route for the acid to attack the connections. With proper precautions, the sal-ammoniac cell is comparatively free from this objection, since when the circuit is open the zinc is not attacked. This is no small merit in a large firing battery; but it is supplemented by another of still greater importance, the electro-motive force of a sal-ammoniac cell is about 1.45 volts, or nearly 50 per cent. higher than that of a dilute sulphuric acid cell.

These advantages early attracted attention, and in June, 1872, experiments were begun at Willets Point which have continued to the present date They have proved satisfactory, and the element has been definitely adopted for several uses in our service.

It was found, in 1874, that the pattern of Leclanché firing battery manufactured by the India Rubber, Gutta Percha and Telegraph Works Company, of London, under the name of the Silvertown firing battery, was so well adapted to the end proposed that no essential modification was necessary. Experience, however, has developed two faults which will be noticed below.

The battery is put up in stout boxes containing ten cells coupled permanently in series with two terminals outside. Each cell is sealed, and contains all the parts needful for action except water, which is to be introduced through two holes in the top prepared for the purpose. The cells are made of ebonite. The zinc plate was at first, cast in the form of a hollow cylinder with six vertical cuts to increase the exposed surface and facilitate the motion of the fluid. The latest pattern is a plain cylinder of rolled zinc. It is surrounded with a packing of sal-ammoniac in powder, enough being inserted to more than saturate the charge of water. Closely fitting inside the zinc is the negative element. Formerly this consisted of a flannel bag containing a carbon plate embedded in a mass of peroxide of manganese and carbon. The present agglomerate form consists of a central carbon hexagon, grooved on each side to fit a cylinder of compressed peroxide of manganese and carbon, 6 inches long

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and .9 of an inch in diameter. The whole are wrapped with a strip of burlap held in place by a couple of rubber bands. Each cell is 4 inches in diameter and 7½ inches high, and should receive about 8 fluid ounces of water when the battery is removed from store for use in service. The following remarks apply to the earlier model, as the modification has not been under trial sufficiently long to justify a decided opinion.

The great fault of the arrangement is the insertion of the powdered sal-ammoniac; but the sealing also is a defect. The salt contains sufficient moisture to slowly encrust the zinc with a coating of oxychloride crystals; which, being insoluble in the added water, increases the internal resistance much above its normal value. To remove these incrustations it is best to cut through the pitch covering, take out and wash the zincs in a strong mixture of muriatic acid and water, re-amalgamate them and replace them. As it may become necessary to repeat this operation, the cells should never be re-sealed. Two bits of marline saturated in paraffine and packed, one between the zinc and ebonite and the other between the zinc and flannel bag, sufficiently prevent evaporation, and are far more convenient than the pitch cover. The cells, when required for use, should be charged with a saturated solution of sal-ammoniac, with a little of the salt added to supply consumption, the zincs being first re-amalgamated.

The electro-motive force of this cell, in perfect order, is about 1.45 volts; and its normal internal resistance, 0.3 ohms, giving for a hundred cell battery the following formula:

$$C = \frac{145}{30 + R_{\prime\prime}}$$

Such a battery will ignite a single service fuze through 260 ohms; and will fire two or more, in series, through 66 ohms. These figures indicate more than three times the strength of current required at most torpedo stations.

The following extracts from numerous recorded tests of this pattern of battery supply data for judging of its endurance and practical efficiency.

The first box was set up on January 15, 1874, by inserting 15 fluid ounces of water in each cell. In three hours their average electro-motive force measured 1.50 volts; and their average internal resistance, 0.29 ohms. The battery was occasionally used for short tests until, on February 23, fluid was noticed leaking from the box. On examination, two cells were found to have overflowed; and when the cork stoppers were removed from a third a strong puff of ammoniacal gas escaped, bringing fluid with it. The cause was probably too tight corking aggravated by an excess of water, and 8 ounces have accordingly been adopted as the proper charge. No recurrence of this difficulty has been noted in any box thus set up.

This box was left standing for over six years, being occasionally used for fuze firing and similar light work. A little water was added two or three times during that period, but no other care was required. Salts forced their way through small cracks in the pitch covering of a few of the cells, but not in sufficient quantities to cause serious inconvenience. The records show that the internal resistance (ten cells) remained nearly constant for about a year, only increasing from 2.9 ohms to 3.4 ohms in fourteen months. This quantity continued to increase very gradually, reaching 12.5 ohms at the end of four years and two months, 15.8 ohms in five years, and 20.5 ohms in six years and three months. The electro-motive force when the battery was inactive hardly changed for five years, and then gradually fell to 1.26 volts. The box was taken apart in May, 1880, and thoroughly cleaned.

A firing battery of forty of these cells (boxes II, III, IV, and V) was set up on May 22, 1874, and has been kept in active service for over six years. On January 24, 1878, sixty more cells were added (boxes VI, VII, VIII, IX, X, and XI), constituting a regular 100-cell battery, such as is proposed for service. It was on this latter date that the ill effect of long storage upon cells charged with dry sal-ammoniac, was discovered. The figures in the following table plainly reveal this troublesome defect in the Silvertown pattern, which causes the zincs to steadily deteriorate when in store. The sal-ammoniac should be added *with the fluid*, and never before. Moreover, the zincs should be freshly amalgamated, which cannot be done with the sealed pattern.

Six-year record of a Leclanché firing battery.

Date.	Mean internal resistance per cell of 10-cell boxes, numbered—											
	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	Battery.
	Ohms.	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*
May 22, 1874	0.51	0.42	0.42	0.51	....	....	....	....	....	....	....	0.47
August 7, 1874	....	....	....	....	....	....	....	....	....	....	....	0.54
October 1, 1874	....	....	....	....	....	....	....	....	....	....	....	0.52
March 6, 1875	0.71	0.71	0.81	0.61	....	....	....	....	....	....	....	0.65
February 16, 1876	....	....	....	....	....	....	....	....	....	....	....	0.90
Add 3 oz. water.												
February 17, 1876	....	....	....	....	....	....	....	....	....	....	....	0.55
November 25, 1876	....	....	....	....	....	....	....	....	....	....	....	0.62
Set up 6 boxes.												
January 24, 1878	....	....	....	....	....	....	....	....	....	....	....	1.03
February 5, 1878	0.75	0.71	0.71	0.40	2.52	2.00	7.35	1.52	1.22	1.22	....	1.27
Add 3 oz. water.												
March 22, 1878	0.47	0.56	0.78	0.32	1.31	0.78	1.33*	0.38	0.61	0.62	....	0.72
April 27, 1878	....	....	....	....	....	....	....	....	....	....	....	0.71
December 24, 1879	0.65	0.88	1.48	0.41	1.28	6.78†	2.18	0.79	1.18	1.00	....	1.60
Cleaned all zincs; 10 oz. fresh fluid.												
March 22, 1880	....	....	....	....	0.58	1.53	0.48	0.40	1.00	....	....	0.96
April 10, 1880	0.58	0.48	1.15	0.69	0.53	2.55	0.50	0.37	0.93	....	1.79‡	1.06
June 11, 1880	0.65	0.43	1.15	0.57	0.49	3.07	0.68	0.36	2.63	....	2.35	1.24
Oct. 8, 1880	0.90	0.55	1.47	0.76	0.68	15.50§	0.90	0.63	3.74	....	4.89	....

* One cell had 4 ohms resistance. It was opened, and the zinc found to be thickly coated with hard crystalline deposit. After cleaning the resistance was 0.2 ohms.

† Opened cells and found zincs thickly incrusted.

‡ Nos. X and XI having several broken zincs were combined as No. X, and a new box, numbered XII, was charged (unopened) with 8 ounces of water per cell on March 30, 1880.

§ One cell dry.

This firing battery has been in constant use with the torpedo operating apparatus under trial at Willets Point, for more than six years. The electro-motive force has remained essentially constant, but a steady increase of internal resistance has been noted. This quantity, always larger than would be proper in a firing battery in actual service, could have been brought to the standard of 0.3 ohms per cell by adding water; but to avoid any troublesome overflow or creeping up of salts, this was not done. A marked difference is to be noted in different boxes, in respect to rate of increase in internal resistance; and even after the cells were opened and thoroughly cleaned in 1880, uniformity was not secured. Experiments are still in progress to determine the causes and the best remedy.

The Leclanché cell is well suited for any use where an intermittent action only is required; and forms suitable for signal and testing batteries have received careful study. As they are treated in the Manual, and have developed no peculiarities differing from those of the firing pattern above described, they will not be noticed in detail here. The gradual increase of internal resistance, and a tendency to corrode the terminals if of copper or lead, are the chief defects.

The following experiments with one of the patterns designed as a signal battery are reported to give an idea of the endurance of the Leclanché cell when working steadily on a circuit of low resistance. The test was similar in all respects to those of the nitric acid and other cells described on page 295. The internal resistance was 3.3 ohms; the electro-motive force before the circuit was closed was 1.46 volts; and the external resistance, including the galvanometer, was 28.1 ohms.

Endurance of Leclanché signal cell working on 28.1 *ohms.*

Time after closing circuit.		External resistance. ($R_{\prime\prime}$)	Electro-motive force.		Strength of current.			Remarks.
			E	$E_{\prime}$	$\frac{E_{\prime}}{R_{\prime\prime}}$	By Gaugain.	Percentage retained.	
h.	*m.*	*Ohms.*	*Volts.*	*Volts.*	*Webers.*	*Webers.*		
0	0	∞	1.459	.....	.....	.....	....	
0	1	28.1	1.170	1.047	0.037	0.037	100	
0	2	28.1	1.113	0.994	0.035	0.035	95	
0	3	28.1	1.077	0.964	0.034	0.034	92	
0	4	28.1	1.048	0.938	0.033	0.033	89	
0	5	28.1	1.024	0.917	0.033	0.032	86	
0	11	28.1	0.935	0.838	0.030	0.029	78	
0	17	28.1	0.875	0.783	0.028	0.027	73	
0	21	28.1	0.843	0.755	0.027	0.026	72	
0	36	28.1	0.761	0.681	0.024	0.024	65	
0	51	28.1	0.702	0.628	0.022	0.022	59	
1	6	28.1	0.657	0.588	0.021	0.020	54	
2	6	28.1	.....	.....	.....	0.018	49	
3	6	28.1	0.541	0.484	0.017	0.017	46	
3	51	28.1	0.528	0.473	0.017	0.016	43	
4	36	28.1	0.551	0.493	0.018	0.016	43	

Although the peroxide of manganese around the carbon plate is of service when the battery is used in a circuit of low resistance, it occupies considerable space and for insulation tests is not necessary. A convenient form for the latter object has been devised and adopted at Willets Point.

The cell consists of a small glass bottle, with a wide mouth, containing a strip of zinc and another of chrome lead, both in a saturated solution of sal-ammoniac. The bottle is about 1 inch in diameter and 3 inches high. A layer of paraffine oil over the surface of the fluid retards evaporation; but it gradually creeps downward over both plates and thus increases the internal resistance enormously, as will soon appear. A better plan, probably, would be to pour a little melted paraffine or beeswax on the fluid, and remove a few drops through a small hole, thus forming a cleaner cover.

One hundred such cells are placed in rows of ten, in a tray 12 by 12 inches. They are held in position by pouring around them melted paraffine. The negative and positive plates of adjacent cells are united by a rivet, and held in place by paraffine dropped in the bottle before the fluid is added.

Five such trays are placed in a case, 18 by 18 by 40 inches high; and two cases, or 1,000 elements, constitute the battery. Each case is insulated by standing on blocks of paraffine, and the leading wires are so connected that any desired number of trays can be switched into circuit at pleasure.

After some preliminary trials, a battery of this description was set up in April, 1874, and has remained in a serviceable condition to date (June, 1880). Occasionally a cell has become dry, but has been at once restored by adding fresh fluid. I think, although the battery has been in frequent use for insulation tests, that a couple of hours would cover all the time expended in such work during the six years. The following figures, selected from the records, give an idea of the rate of gradual deterioration. They represent the mean values for a single cell:

May 2, 1874. E = 0.45 volts R, = 25 ohms.
April 27, 1876. E = 0.41 volts R, = 125 ohms.
April 6, 1878. E = 0.34 volts R, = 355 ohms.
June 11, 1880. E = 0.30 volts R, = 740 ohms.

One tray containing 100 of these cells was charged with dilute sulphuric acid—1 part of acid to 100 parts of water—for comparison. It gave a lower internal resistance and a higher electro-motive force, at first; but in about a year and a half it totally failed.

In fine, I know of no combination more enduring and more convenient for occasional insulation tests, than the pattern of sal-ammoniac cell just described.

The Peroxide of Lead Cell—single fluid.—In 1876, Charles T. Chester introduced in New York, under the name of "magazine battery," the De La Rive peroxide of lead cell. This element is remarkable for its high electro-motive force and, among single fluid cells, for its constancy of action. The depolarizing substance is expensive; and,

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as put upon the market, it contained traces of nitric acid which proved destructive to the zincs. Notwithstanding the latter defect, the cell exhibited incontestable merits. By comparing the figures in the following table with those just given for the Leclanché cell, a good idea will be formed of the relative endurance and strength of the two elements, which were similar in dimensions, working on similar external resistances.

Two cells were tested in the manner already described. In both, the negative plate consisted of a carbon plate, embedded in peroxide of lead contained in a porous cup. This cup was 3 inches in diameter and 5.5 inches high. The positive plate was the common Leclanché cylinder of zinc, ½ inch in diameter and 7 inches long. They were placed in a cylindrical glass cell, 4 inches in diameter and 6 inches high, half filled with fluid, which for one cell was dilute sulphuric acid (1 part of acid to 14 parts of water); and for the other cell, a saturated solution of sal-ammoniac. The internal resistance of the former at the first closing of the circuit was 1.7 ohms; and at the end of the trial, 7.5 ohms. These figures for the sal-ammoniac cell were 2.0 and 2.5 ohms, respectively.

These cells were allowed to stand for a few days without closing the circuit, and the change in electro-motive force was noted by Law's method, as follows:

February 19, 1876. Acid cell, 2.305 volts; sal-ammoniac cell, 1.800 volts.
February 24, 1876. Acid cell, 2.128 volts; sal-ammoniac cell, 1.664 volts.
February 25, 1876. Acid cell, 2.057 volts; sal-ammoniac cell, 1.689 volts.
February 26, 1876. Acid cell, 1.994 volts; sal-ammoniac cell, 1.642 volts.

They were then placed at work continuously for five days. After a rest of two days and a re-amalgamation of the zincs, which had begun to suffer, the circuit was again closed, the electro-motive force being 1.580 and 1.490 volts, respectively.

Endurance of the peroxide of lead cell working on 28.4 *ohms.*

Time after closing circuit.	SULPHURIC ACID CELL.					SAL-AMMONIAC CELL.				
	Electro-motive force.		Strength of current.			Electro-motive force.		Strength of current.		
	E	E,	$\frac{E_{,}}{R_{,,}}$	By Gaugain.	Percentage retained.	E	E,	$\frac{E_{,}}{R_{,,}}$	By Gaugain.	Percentage retained.
d. h. m.	*Volts.*	*Volts.*	*Webers.*	*Webers.*		*Volts.*	*Volts.*	*Webers.*	*Webers.*	
0 00 01	1.702	1.607	0.056	0.055	100	1.350	1.260	0.045	0.045	100
0 01 00	1.625	1.534	0.054	0.052	95	1.179	1.100	0.039	0.038	85
0 02 00	1.575	1.487	0.052	0.051	93	1.163	1.086	0.039	0.037	82
0 03 00	1.575	1.487	0.052	0.050	91	1.156	1.079	0.038	0.037	82
0 04 00	1.525	1.440	0.050	0.047	86	1.179	1.100	0.039	0.037	82
0 12 00	.....	.....	.....	0.045	82	.....	.....	.....	0.032	71
0 23 00	1.398	1.320	0.046	0.045	82	0.843	0.787	0.028	0.027	60
1 11 00	.....	.....	.....	0.045	82	.....	.....	.....	0.025	56
1 23 00	1.371	1.294	0.045	0.044	80	0.742	0.693	0.025	0.024	53
2 04 00	1.328	1.254	0.044	0.043	78	0.750	0.700	0.025	0.024	53

Endurance of the peroxide of lead cell working on 28.4 *ohms*—Continued.

Time after closing circuit.	SULPHURIC ACID CELL.					SAL-AMMONIAC CELL.				
	Electro-motive force.		Strength of current.			Electro-motive force.		Strength of current.		
	E	$E_{,}$	$\frac{E_{,}}{R_{,,}}$	By Gaugain.	Percentage retained.	E	$E_{,}$	$\frac{E_{,}}{R_{,,}}$	By Gaugain.	Percentage retained.
d. h. m.	*Volts.*	*Volts.*	*Webers.*	*Webers.*		*Volts.*	*Volts.*	*Webers.*	*Webers.*	
2 23 00	1.328	1.254	0.044	0.043	78	0.750	0.700	0.025	0.024	53
3 04 00	1.316	1.243	0.044	0.041	75	0.750	0.700	0.025	0.024	53
4 00 00	1.250	1.180	0.041	0.041	75	0.728	0.680	0.024	0.024	53
4 04 30	1.244	1.174	0.041	0.039	70	0.764	0.718	0.025	0.023	52
5 00 00	1.116	1.054	0.037	0.037	67	0.723	0.675	0.024	0.024	53
Rest for 2 days.										
5 00 01	1.260	1.190	0.042	0.042	78	0.941	0.879	0.031	0.032	71
5 00 07	1.232	1.163	0.041	0.041	75	0.797	0.744	0.026	0.027	60
5 02 45	1.115	1.054	0.037	0.035	65	0.702	0.656	0.023	0.022	50
6 00 00	.....	.....	.....	0.031	56	.....	.....	.....	0.023	51
7 02 00	.....	.....	.....	0.023	42	.....	.....	.....	0.023	51
8 04 30	.....	.....	.....	0.023	42	.....	.....	.....	0.022	49
9 00 00	.....	.....	.....	0.022	40	.....	.....	.....	0.022	49
10 02 00	.....	.....	.....	0.021	38	.....	.....	.....	0.022	49
12 01 00	.....	.....	.....	0.020	36	.....	.....	.....	0.022	49
14 00 00	.....	.....	.....	0.020	36	....	.....	.....	0.023	51
15 23 00	.....	.....	.....	0.018	33	.....	.....	.....	0.021	47
17 23 00	.....	.....	.....	0.018	33	.....	.....	.....	0.022	49
18 23 00	.....	.....	.....	0.017	31	.....	.....	.....	0.020	44
22 02 00	.....	.....	.....	0.015	27	.....	.....	.....	0.022	47
28 23 00	.....	.....	.....	0.012	22	.....	.....	.....	0.020	44
30 23 00	.....	.....	.....	0.012	22	.....	.....	.....	0.021	46
32 23 00	.....	.....	.....	0.011	20	.....	.....	.....	0.021	46

At the end of the thirty-third day both cells were exhausted, new zincs and fluids being required. About a minute after the circuit was finally broken the electro-motive force of the acid cell was 0.471 volts, and of the other, 0.803 volts.

The Sesquioxide of Iron Cell—single fluid.—Early in 1875, Mr. Beardslee drew my attention to a native earth of New Jersey, consisting largely of sesquioxide of iron. He found it so useful as a packing round the negative plate of an earth battery working an electrical clock, that the following experiments were made at Willets Point to test its depolarizing power. It was directly compared with pure sesquioxide; and by reference to the tables showing the action of the Leclanché and peroxide of lead cells an idea may be formed of the relative merit of the three depolarizing agents as packing round the carbon plate, since all the cells were similar in dimensions and working on similar external resistances. A saturated solution of sal-ammoniac was used as the exciting fluid. Before closing the circuit, the cell containing the pure material indicated an electro-motive force of 1.508 volts, and that charged with the earth, 1.184 volts; the corresponding internal resistances being 1.9 ohms and 2.9 ohms, respectively.

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Endurance of the sesquioxide of iron cell working on 28 ohms.

Time after closing circuit.	PURE SESQUIOXIDE OF IRON.					IMPURE SESQUIOXIDE OF IRON.				
	Electro-motive force.		Strength of current.			Electro-motive force.		Strength of current.		
	E	E,	$\frac{E,}{R,,}$	By Gaugain.	Percentage retained.	E	E,	$\frac{E.}{R,,}$	By Gaugain.	Percentage retained.
d. h. m.	*Volts.*	*Volts.*	*Webers.*	*Webers.*		*Volts.*	*Volts.*	*Webers.*	*Webers.*	
0 0 01	1.380	1.290	0.046	0.047	100	0.867	0.783	0.028	0.026	100
0 0 02	.....	1.277	0.046	0.047	100	.....	0.760	0.027	0.026	100
0 0 03	.....	1.283	0.046	0.047	100	.....	0.760	0.027	0.025	96
0 0 04	.....	1.265	0.045	0.047	100	.....	0.760	0.027	0.025	96
0 0 05	.....	1.248	0.045	0.046	98	.....	0.760	0.027	0.024	92
0 0 16	.....	.....	.....	0.042	90	.....	.....	.....	0.023	88
0 0 30	.....	.....	.....	0.041	87	.....	.....	.....	0.021	81
0 1 00	.....	.....	.....	0.038	81	.....	.....	.....	0.019	73
0 1 30	.....	1.000	0.041	0.035	74	.....	0.604	0.021	0.019	73
Rest 20 hours.										
0 1 31	1.430	1.339	0.047	0.047	100	1.038	0.938	0.033	0.031	119
0 1 32	.....	1.332	0.047	0.047	100	.....	0.920	0.033	0.031	119
0 1 33	.....	1.332	0.047	0.047	100	.....	0.903	0.032	0.030	115
0 1 34	.....	1.320	0.047	0.047	100	.....	0.890	0.031	0.029	111
0 1 35	.....	1.313	0.047	0.047	100	.....	0.880	0.031	0.029	111
0 1 46	.....	1.265	0.045	0.045	96	.....	0.788	0.028	0.026	100
0 2 00	.....	.....	.....	0.044	94	.....	.....	.....	0.023	88
0 2 30	.....	.....	.....	0.039	83	.....	.....	.....	0.022	85
0 3 00	.....	.....	.....	0 036	80	.....	.....	.....	0.021	81
0 4 00	.....	0.792	0.028	0.028	60	.....	0.645	0.023	0.021	81
0 5 00	.....	.....	.....	0.023	50	.....	.....	.....	0.021	81
0 6 00	.....	.....	.....	0.020	43	.....	.....	.....	0.021	81
0 6 45	.....	0.533	0.019	0.018	38	.....	0.658	0.023	0.021	81

These figures show a decided recuperative power in this element, and no inconsiderable absolute merit.

The Sulphate of Copper Cell—two-fluid.—This element, of which the Daniell is the original type, is universally employed in telegraphy in this country, and is so well known that it requires little notice here. It has no rival for supplying a continuous and uniform current of moderate strength, the desideratum with a signal battery operating a group of torpedoes on a closed circuit. For this object a rather low internal resistance and ease of manipulation is required; and many measurements and comparative tests of the numerous patterns in the market have been made with a view to selecting the best.

The pattern having the smallest internal resistance was a very old one, designed probably fifty years ago. It consisted of a copper jar 5½ inches in diameter and 7 inches high, with a concentric cylinder of the same metal soldered to the bottom. The zinc, enveloped in a bladder, was inserted in the annular cavity, which was 1 inch wide. The internal resistance of this cell did not exceed 0.3 ohms; and it would fire an ordinary platinum fuze readily through a short leading wire.

The history of the sulphate of copper battery shows that the first modifications in the original form (which was similar to the above) were to reduce the copper surface and to replace the bladder with a porous earthen cup, both of which had the effect to increase the internal resistance. The deposit of copper on the porous cup proved troublesome and led to its virtual abandonment, at least in this country, where the gravity form, soon to be described, has superseded all others.

With the Minotto form of the cell, sand, sawdust, and sponge have been tried as separating media. They are all convenient for movable batteries; but nodules of copper are apt to extend toward the zinc plates, and for stationary cells experience has shown that the type is not to be recommended. When used, a disc of flannel embedded in the separatrix will be found of decided advantage in checking the troublesome copper deposit. The internal resistance of this class of cells is usually about 6 or 7 ohms; and a battery of a half dozen elements has been kept at work on an external circuit of about 60 ohms without any material variation in the strength of current for several months. An English pattern, having large plates (zincs of a grid-iron form) and an exceptionally thin separatrix of sawdust, gave an internal resistance of only 1.5 ohms; but its endurance was correspondingly shortened. An American variety, known as the Eagle battery, consists of a lead vessel which contains the materials and also acts as the negative plate. The internal resistance is low, but the vessel is liable to leak from the action of the sulphuric acid upon impurities in the lead.

The modern type of the sulphate of copper cell acts on the gravity principle. The copper plate rests at the bottom of the cell surrounded by a saturated solution of cupric sulphate. The zinc is suspended above in a dilute solution of zinc sulphate. These two aqueous solutions, if carefully protected against mechanical disturbance, remain separate by virtue of a difference of specific gravity, and the troublesome copper deposit on the separatrix is thus prevented.

There are many forms of the gravity battery, known by the names of their designers or patentees, but the differences are all in minor details of arrangement.

The Callaud form (French) was probably the original type. The copper electrode is composed of strips 1.5 inches wide, folded together in the form of a four-pointed star and supported edge upward to preserve the surface free from dropping impurities. The zinc is cast in a similar form with the points united, for strength, by a circumscribing band. Both are suspended from a wooden strip laid across the mouth of the jar. The chief objections to this pattern are rapid evaporation, and the difficulty of adding cupric sulphate without disturbing the solutions. A film of oil reduces the former, but it makes the cell dirty and hard to keep in order.

The Hill cell is an American pattern of this battery. The copper in the form of a circular disc rests on the bottom, and is connected with the exterior by a copper wire coated with gutta-percha. The zinc is a circular disc hollowed on the bottom, and pierced by a central hole to facilitate the escape of oxygen and permit the introduction of cupric sulphate. It is suspended horizontally, about 3½ inches above the copper, hanging from the edge of the jar by a brass hook which also constitutes the negative pole. By thus dispensing with the wooden strip, all danger of creeping of salts from one pole to the other is avoided.

The Meidenger, or, as it is known in this country, the Chester enduring cell, consists of an ordinary 6 by 8 inch jar, on the bottom of which rests a conical-shaped tumbler. The copper cylinder is contained in this tumbler and is connected with the exterior by an insulated wire forming the positive pole. The zinc cylinder is capped with a flat disc which forms a cover to the jar and thus prevents evaporation. Through a hole in the center of this cover a glass cylinder extends down into the tumbler and there terminates in a small hole about ⅛ of an inch in diameter. This glass is designed to hold a few crystals of sulphate of copper which dissolve gradually and furnish the needful supply round the copper plate. The internal resistance of this pattern is high, but it works well in a circuit of large resistance.

This effort to prevent the mixing of the solutions by mechanical means was followed by the Lockwood patent in 1873. The copper plate consists of two flat spirals of copper wire united by an upright copper rod. The lower coil rests on the bottom of the jar, and is connected with the exterior by an insulated wire forming the positive pole. The zinc is suspended from the top of the jar by a frame resting on its edges. In setting up the battery, the full supply of sulphate of copper is placed between the spirals. The chief deposit is upon the lower spiral, the function of the upper being to reduce the diluted solution near the junction of the two and thus prevent any copper from reaching the zinc. The internal resistance varies from 4 to 15 ohms, according to the mode of setting up, and on a closed circuit of low resistance the battery does good service.

After the appearance of the Lockwood cell, Chester modified his "enduring" element by suppressing the glass tumbler, enlarging his copper cylinder and supporting it on legs to raise the top to the point of junction of the two fluids. He also cut off the bottom of his glass tube so that it became a simple pipe for introducing the crystals of sulphate of copper to the bottom of the jar without disturbing the solutions. These changes reduced the internal resistance to two or three ohms, and improved the element for a circuit of low resistance.

The pattern of gravity cell known as the Watson is the latest introduced into our market (May, 1876); and it is perhaps the best form for use as a signal battery. It consists of an ordinary 6 by 8 inch glass jar, covered by a porcelain disc. The zinc, annular and massive, is attached to the cover by metal rods. The negative element is an inverted lead funnel. The cylindrical part is 5 inches long and 2 inches in diameter, and is protected by paint where it traverses the solution of zinc sulphate. The cone is 5.5 inches in diameter at its base, where it rests on the bottom of the jar, and is pierced by several holes to permit the free passage of the solution of cupric sulphate. A large deposit of copper forms on this cone, and it is well to cut one side open to avoid any wedging in the jar in consequence. The internal resistance varies from 3 to 6 ohms.

This form combines all the merits of its various predecessors, viz, no porous cell, no evaporation, negative plate of large surface extending entirely through the solution of cupric sulphate, facility of charging whenever desirable, a receptacle for the droppings from the zinc where they do not mingle with the crystals of the sulphate or cover the negative plate, and lastly, convenient binding posts on the cover. It has been provisionally adopted as the best form of signal battery for the Torpedo Service.

The Chloride of Silver Cell—single fluid.—This cell has recently been highly recommended in Europe as a convenient element for testing insulation resistance; and has attracted attention from the enormous battery (12,000 cells) used by Mr. Warren De La Rue in his experiments upon electricity of high potential.

In 1878 a battery of 200 testing cells was purchased from Clarke, Muirhead & Co., of London, for trial. They were arranged by fifties in trays 14 by 7.5 by 5 inches. Each cell consisted of a glass cylinder 0.8 inches in diameter and 2.5 inches high, containing a small rod of zinc and a strip of silver tipped with melted chloride of silver, immersed in a saturated aqueous solution of sal-ammoniac. Evaporation was checked by a cork which closed the cell and supported the electrodes. A strip of paper, wound loosely around the negative plate and gummed at its edges, served to separate the latter from the zinc.

This cell has an electro-motive force of about 1.14 volts and an internal resistance of about 35 ohms, but the latter gradually increases from the oxychloride crystals which form on the zincs.

The endurance of this battery disappointed the expectations formed from the notices in the English electrical journals. In a couple of months dry cells began to appear, and from the manner in which they were coupled together it was not easy to add fluid. The paper seemed to aggravate the difficulty, and salts soon made their appearance around the corks. To obviate this difficulty, the latter were soaked in paraffine oil, but apparently without any advantage; and after two or three renewals, for which the construction is very ill adapted, the whole battery was taken apart to be cleaned and tried in a modified form. Experiments with it are still in progress.

The Clark Standard Cell—single fluid.—This cell is generally accepted as the best voltaic standard for electro-motive force; and in measurements of this quantity it has been used almost exclusively at Willets Point.

The cell, after extensive trials, was proposed as a standard, by Mr. Latimer Clark,

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in a paper read before the Royal Society, in 1872. As this paper is not readily accessible, the following quotation, which sufficiently describes the composition of the element, is given:

"The battery is composed of pure mercury as the negative element, the mercury being covered by a paste made by boiling mercurous sulphate in a thoroughly saturated solution of zinc sulphate, the positive element consisting of pure zinc resting on the paste. The best method of forming this element is to dissolve pure zinc sulphate to saturation in boiling distilled water. When cool, the solution is poured off from the crystals and mixed to a thick paste with pure mercurous sulphate, which is again boiled to drive off any air; this paste is then poured on to the surface of the mercury previously heated in a suitable glass cell; a piece of pure zinc is then suspended in the paste, and the vessel may be advantageously sealed up with melted paraffine wax. Contact with the mercury may be made by means of a platinum wire passing down a glass tube cemented to the inside of the cell, and dipping below the surface of the mercury, or more conveniently by a small external glass tube blown on to the cell, and opening into it close to the bottom. The mercurous sulphate (Hg_2SO_4) can be obtained commercially (the author has obtained it from Messrs. Hopkin & Williams, 5 New Cavendish street); but it may be prepared by dissolving pure mercury in excess in hot sulphuric acid at a temperature below the boiling point: the salt, which is a nearly insoluble white powder, should be well washed in distilled water, and care should be taken to obtain it free from the mercuric sulphate (persulphate), the presence of which may be known by the salt turning yellowish on the addition of water.

"The electro-motive force of the elements thus formed is remarkably uniform and constant, provided the elements be not connected up and allowed to become weak by working. A long series of comparisons was made between various elements, some of which had been made many months, and it was found that the greatest variation among them all did not differ from the mean value more than one-thousandth part of the whole electro-motive force; such a large difference was, however, very unusual, and might have been due to slight differences of temperature.

"Several experiments were made to determine the variation of the electro-motive force produced by temperature, from the mean of which it appears that the electromotive force decreases with increased temperature in the ratio of about .06 per cent. for each degree Centigrade; for example, an element gave relative values of .9993 at 0° C. and .9112 at 100° C., between which limits the decrease appeared nearly proportional to the increments of temperature. These results, however, might be verified with advantage.

"The element is not intended for the production of currents, for it falls immediately in force if allowed to work on short circuit. It is intended to be used only as a standard of electro-motive force with which other elements can be compared by the use of the electrometer or condenser, or other means not requiring the use of a prolonged current. The author finds that the most delicate method of making these measurements is by means of his potentiometer (see 'A Treatise on Electrical Measurement,' by Latimer Clark, London, 1868, p. 106).

"As it was desirable to determine the value of the force of the element in absolute measure and in terms of the British Association units, a very careful series of measurements was made by the electro-dynamometer constructed for the British Association Committee and referred to in their report for 1867, and also by means of a sine galvanometer of somewhat novel form.

"The following tables give the results obtained:

* * * * * *

	Volts.
"We have, therefore, the mean value of the electro-motive force of the standard cells, as determined by the electro-dynamometer, 18 observations	1.45735
As determined by the sine galvanometer, 13 observations	1.45621
Mean value	1.45678

"Or since no importance can be attached to the figures beyond the third place of decimals, 1.457 volt or British Association unit of electro-motive force, equal to 145,700 absolute electro-magnetic units.

"The value of H, the horizontal component of the earth's magnetic intensity, a knowledge of which is necessary for the determination by the sine galvanometer, was kindly supplied for each day by the Astronomer Royal"

These directions have been scrupulously followed in preparing the standard cells for use at Willets Point.

To avoid any deterioration the custom has been to keep at least two cells on hand, set up on different dates. So soon as any discrepancy in their indications appears, a new one is set up, and the defective cell is condemned.

To procure in our market protosulphate of mercury sufficiently pure to give no indications of Turpeth mineral when water is added, was found so difficult that a supply was imported from the manufacturer named by Mr. Clark, in his paper. This has given perfect satisfaction, being identical in its indications with a small sample of the pure salt prepared at Willets Point.

This cell is remarkably constant when carefully set up with pure chemicals and used exclusively with a condenser, so as never to close its circuit; and the convenience is very great of having always at hand in the laboratory so trustworthy a standard of electro-motive force. The following record will give a correct idea of its constancy under such circumstances.

On November 24, 1875, a cell (No. III) was set up in this manner, using the imported protosulphate. On December 8, 1876, another cell (No. IV) was prepared in like manner, and compared with No. III by charging a half microfarad condenser

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for 30 seconds and discharging through a Thomson galvanometer without a shunt, the temperature being 48° Fahr.

	Cell III.	
Swings	328	190
	328	192
	329	190
	329	192
	328	190
	328	191
Mean	328. 3	190. 8
Air correction	34. 4	
Corrected swing	362. 7 divisions.	

	Cell IV.	
Swings	330	203
	330	189
	330	203
	330	190
Mean	330. 0	196. 2
Air correction	33. 4	
Corrected swings	363. 4 divisions.	

These measurements indicate a discrepancy of 0.003 volts between the two standards, proving that no sensible deterioration had occurred in No. III during the year.

On April 10, 1878, a fresh cell (No. I) was set up and compared in like manner with No. III, showing a difference of 0.032 volts in the electro-motive force (1.454 volts) of the element.

On October 16, 1879, another new cell was compared in the same way with No. III. The difference between them was only 0.011 volts in an electro-motive force of 1.454 volts. On January 19, 1880, these cells were again compared, and they differed only 0.024 volts, the sign being different from that of the October comparison.

On the same day (January 19, 1880), No. III was compared with a cell set up three months before, using protosulphate of mercury prepared at Willets Point. The difference between these two cells was 0.012 volts. Tested again on April 10, 1880, they showed the same numerical difference, but with a contrary sign.

In fine, these tests prove that cell No. III remained without sensible deterioration from the date on which it was set up (November, 1875) until April, 1880. During this long period it was kept in a dark closet, at an equable temperature; and, as it was used only with a condenser, its circuit was never closed even for an instant. It should be added that similar cells treated in like manner have often showed a falling off in electro-motive force after standing a year or more. It is, therefore, necessary to verify the condition of a standard cell by occasionally comparing it with elements newly set up.

The Secondary Cell—single fluid.—To the class of powerful and momentary batteries belongs a very peculiar type, in which advantage is taken of the phenomenon of polarization to store up the work performed by two or three small constant elements, acting for a considerable time, in such a shape as to be readily transformed into a powerful current acting for a short time.

The name secondary battery has been given to this device, which is analogous to the condenser used for collecting powerful electric charges by the continuous work of a feeble generator, like a frictional machine. Nothing resembling the augmentation of the charge by induction occurs; but an effect similar to the residual charge is exhibited, due, probably, to a temporary reversal of superficial polarization.

In its best form a secondary cell, as recently perfected by M. Planté, consists of a sealed jar containing dilute sulphuric acid, one part to ten by volume. Within it are placed two lead plates, carefully insulated by rubber bands from each other, but rolled in a common spiral which is suspended vertically from two wires, each leading from one of the plates to a terminal binding screw.

Like any other cells, these may be coupled either in series or in multiple arc, but for charging they should be joined only in the latter manner. Three Bunsen cells are sufficient, to charge, in ten minutes, a battery of twenty cells capable, when discharged in series, of producing a momentary effect equivalent to that of thirty Bunsen elements.

To accomplish this result, if the cells are new, a certain preliminary "formation" is necessary. That is, the current of the charging battery should several times be sent for about an hour in one direction, and reversed for a like period. The more times such reversals are repeated, and the older the plates become, the better will be the results obtained.

The utility of these preliminary reversals arises from the alternate formation of plumbic peroxide, and its reduction to plumbic protoxide, on the opposed surfaces; a gradually thickening coat is thus formed that enables them the better to retain the oxygen and hydrogen to which the secondary current owes its origin.

After the plates are thus well coated, it is better to use for ordinary charging a current unchanging in direction. This state is indicated when both plates are covered with an adherent reddish coat, and when no escape of the gases occurs until about six or eight minutes after the charging current is sent through them. When the gases begin to appear freely the battery is charged.

These cells improve with age, and no renewal of the solution is requisite.

The strong secondary action continues on a short circuit for ten or fifteen minutes; and for a longer time, if more external resistance be added. The plates retain their charge for long periods, if the circuit is kept open, or only closed for a few instants at a time. In a word, the available electrical work which can be performed by the secondary battery is only about 10 per cent. less than that expended in charging it.

After the plates are once well formed, it is not necessary to employ a strong bat-

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tery, like the Bunsen element, to charge them. Feeble cells, like Daniell's, will serve the same purpose, only more cells and more time should be allowed.

These plates are supplied by M. Planté as follows: Large single cells having plates each 9 by 17 inches. Twenty cell batteries arranged with a commutator so that they can all be coupled in series, or in multiple arc, by a single movement. The size of the plates is 4.5 by 7 inches Lastly, the Briquet de Saturne, or lead tinder box, which contains a small secondary battery kept constantly charged by three small Daniell cells. By closing the circuit through a short piece of platinum wire placed across the wick of a taper, light may be instantly obtained from the reddening of the wire.

The following measurements, made on a Briquet de Saturne at the Torpedo School, will explain precisely how so surprising a result as the reddening of a platinum wire (No. 33 B. W. G.) can result from the action of three little Daniell cells. The measured electro-motive force of each of these cells was 1.02 volts; the internal resistance was 26.83 ohms; the electro-motive force of the secondary cell was 1.96 volts; and its internal resistance was 0.29 ohms. Therefore the charging current, which stored up its work in the secondary cell, was:

$$C = \frac{3 \times 1.02}{3 \times 26.83 + 0.29} = \frac{3.06}{80.79} = 0.038 \text{ webers.}$$

The resistance of the platinum wire and connections was 0.76 ohms. Therefore the current which lighted the taper was:

$$C = \frac{1.96}{0.29 + 0.76} = 1.87 \text{ webers.}$$

That is, although the secondary cell had only about two-thirds of the electromotive force of the charging battery, *the internal resistance of the latter was eliminated*—which accounts for the strong current developed through its agency.

As a firing battery in sea coast defence, this type would offer the great advantage of restricting attention to two or three charging cells; but experience has shown that there is danger of occasional contacts occurring between the plates in the cells, which are troublesome to correct;. and, upon the whole, it has been thought better to use a less complex arrangement.

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APPENDICES.

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APPENDIX A.

DETAILS OF EXPERIMENTS WITH THE RINGS.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
1	Explosive, mortar powder; ring, 3 foot; charge, 50 pounds; submergence, 30 feet; depth of water, 30 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 10 Dowse-Smith fuzes (powder). Effects: Fired on September 8, 1870, the apparatus slung from a pole projecting from bow of ponton; water rose in a 5-foot dome, with central jet 30 feet high.	......	......	......	......	......	......	
		......	......	......	......	......	......	
		1	3	0.4	0.057	5.24	3,012	Nos. 1 and 2 gauges not used.
		1	4	0.4	0.099	10.76	4,871	
		1	5	0.4	0.039	3.26	2,195	
		1	6	0.4	0.040	3.36	2,242	
		2	Torpedo.	0.5	0.286	4.44	2,702	
		2	Do.	......	......	......	......	Gauge lost.
2	Explosive, mortar powder; ring, 5 foot; charge, 50 pounds; submergence, 16 feet; depth of water, 31.5 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 10 Dowse-Smith fuzes (powder). Effects: Fired October 15, 1870, the apparatus supported by a strong oil keg; case probably leaked, giving too small a record; the keg was not injured by explosion.	1	1	0.4	0.005	......	......	
		1	2	0.4	0.013	......	......	
		1	3	0.4	0.000	......	......	
		1	4	0.4	0.011	......	......	
		1	5	0.4	0.022	......	......	
		1	6	0.4	0.008	......	......	
		1	Torpedo.	0.4	0.077	......	......	
		1	Do.	0.5	0.020	......	......	
3	Explosive, mortar powder; ring, 3 foot; charge, 100 pounds; submergence, 15 feet; depth of water, 30 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 20 Dowse-Smith fuzes (powder). Effects: Fired October 19, 1870, the apparatus suspended from strong oil keg; jet about 180 feet high; keg was crushed, letting ring fall to the bottom.	1	1	0.4	0.308	61.73	15,610	
		1	2	0.4	0.192	27.89	9,190	
		1	3	0.4	0.111	12.59	5,407	
		1	4	0.4	0.117	13.57	5,682	
		1	5	0.4	0.205	30.98	9,858	
		1	6	0.4	0.272	49.70	13,508	
		1	Torpedo.	0.4	......	......	......	Lead slipped.
		1	Do.	0.5	......	......	......	Do.
4	Explosive, mortar powder; ring, 3 foot; charge, 100 pounds; submergence, 45 feet; depth of water, 100 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 20 Dowse-Smith fuzes (powder). Effects: Fired October 19, 1870, the apparatus suspended by strong oil keg, which was not injured; jet about 120 feet high; case well broken.	1	1	0.4	0.152	19.84	7,323	
		1	2	0.4	0.101	11.06	4,961	
		1	3	0.4	0.119	13.90	5,775	
		1	4	0.4	0.154	20.22	7,416	
		1	5	0.4	0.220	34.82	10,655	
		1	6	0.4	0.213	32.95	10,271	
		1	Torpedo.	0.4	0.075	7.42	3,802	
		1	Do.	0.4	0.042	3.56	2,329	
5	Total failure by reason of leakage.							
6	Explosive, mortar powder; ring, 5 foot; charge, 50 pounds; submergence, 31 feet; depth of water, 80 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 10 Dowse-Smith fuzes (powder). Effects: Fired May 12, 1871; first use of iron buoy and ponton with windlass; the charge was submerged an hour, causing case to leak; attached torpedo gauges to wooden floats, which were torn apart.	1	1	0.4	0.010	......	......	
		1	2	0.4	0.008	......	......	
		1	3	0.4	0.008	......	......	
		1	4	0.4	0.009	......	......	
		1	5	0.4	0.007	......	......	
		1	6	0.4	0.013	......	......	
		3	7	0.4	0.012	......	......	Gauge lost.
		3	8	0.4	0.031	......	......	Do.
7	Total failure by reason of leakage.							

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
8	Explosive, mortar powder; ring, 5 foot; charge, 50 pounds; submergence, 31 feet; depth of water, 70 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 10 Dowse-Smith glycerine fuzes. Effects: Case evidently leaked, as its fragments were large and not compressed, Hereafter all will be braced inside.	1	1	0.4	0.019	......	......	
		1	2	0.4	0.006	......	......	
		1	3	0.4	0.010	......	......	
		1	4	0.4	0.006	......	......	
		1	5	0.4	0.005	......	......	
		1	6	0.4	0.005	......	......	
		3	7	0.4	0.003	......	......	
		3	8	0.4	0.008	......	......	
		1	Torpedo.	0.4	0.008	......	......	
		1	Do.	0.4	0.033	......	......	
9	Explosive, mortar powder; ring, 5 foot; charge, 100 pounds; submergence, 31 feet; depth of water, 60 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 10 Dowse-Smith fuzes (powder). Effects: Buoy thrown say 25 feet upward in the jet; case broken in small bits; used raw-hide ropes to recover torpedo gauges.	1	1	0.4	0.040	3.36	2,242	
		1	2	0.4	0.065	6.20	3,373	
		1	3	0.4	0.045	3.86	2,460	
		1	4	0.4	0.062	5.83	3,238	
		1	5	0.4	0.040	3.36	2,242	
		1	6	0.4	0.039	3.26	2,195	
		3	7	0.4	0.004	0.001	15	
		3	8	0.4	0.014	0.028	93	
		1	Torpedo.	0.4	0.236	39.12	11,514	
		1	Do.	0.4	0.116	13.40	5,636	
10	Explosive, mortar powder; ring, 5 foot; charge, 50 pounds; submergence, 31 feet; depth of water, 83 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 10 Dowse-Smith glycerine fuzes. Effects: Case well broken.	1	1	0.4	0.045	3.86	2,460	
		1	2	0.4	0.028	2.17	1,674	
		1	3	0.4	0.033	2.65	1,914	
		1	4	0.4	0.038	3.15	2,149	
		1	5	0.4	0.027	2.08	1,625	
		1	6	0.4	0.042	3.56	2,329	
		3	7	0.4	0.018	0.009	43	
		3	8	0.4	0.158	0.16	295	
		1	Torpedo.	0.4	0.113	12.81	5,498	
		1	Do.	0.4	0.079	7.98	3,990	
11	Explosive, mortar powder; ring, 5 foot; charge, 150 pounds; submergence, 31 feet; depth of water, 83 feet; case, wooden, 1-inch pine; ignition, Smith's machine, 30 Dowse-Smith fuzes (powder). Effects: Buoy thrown 30 feet upward in the jet, which was large; shock felt half a mile distant.	1	1	0.4	0.111	12.59	5,407	
		1	2	0.4	0.112	12.75	5,453	
		1	3	0.4	0.120	15.57	6,231	
		1	4	0.4	0.133	16.32	6,428	
		1	5	0.4	0.155	20.41	7,463	
		1	6	0.4	0.155	20.41	7,463	
		3	7	0.4	0.064	0.046	129	
		3	8	0.4	0.107	0.091	202	
		1	Torpedo.	0.4	0.310	62.54	15,746	
		1	Do.	0.4	0.119	13.90	5,775	
12	Explosive, mortar powder; ring, 5 foot; charge, 100 pounds; submergence, 31 feet; depth of water, 90 feet; case, wooden, 1-inch pine; ignition, Smith's machine, 20 Dowse-Smith glycerine fuzes. Effects: Ring struck by cable gauge socket; buoy thrown up about 25 feet in jet.	1	1	0.4	0.128	15.42	6,169	
		1	2	0.4	0.102	11.21	5,004	
		1	3	0.4	0.119	13.90	5,775	
		1	4	0.4	0.101	11.06	4,961	
		1	5	0.4	......	......	......	
		1	6	0.4	0.101	11.06	4,961	
		3	7	0.4	0.076	0.058	150	
		3	8	0.4	0.075	0.057	148	
		1	Torpedo.	0.4	0.158	21.01	7,609	
		1	Do.	0.4	0.155	20.41	7,463	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
13	Explosive, O. P. Co. compound and mortar powder; ring, 5 foot; charge, 18+18 pounds; submergence, 31 feet; depth of water, 120 feet; case, wooden, 12-inch cube of 1-inch pine; ignition, Smith's battery, 10 Dowse-Smith glycerine fuzes. **Effects**: Sharp explosion, having three distinct sounds; box pulverized; many fish killed; broke 1-inch iron bolt, and let ring fall on edge.	1	1	0. 4	0. 192	75. 47	17, 847	
		1	2	0. 4	0. 174	65. 26	16, 199	
		1	3	0. 4	0. 198	79. 16	18, 423	
		1	4	0. 4	0. 195	77 22	18, 120	
		1	5	0. 4	0. 191	74. 88	17, 756	
		1	6	0. 4	0. 210	87. 00	19, 620	
		3	7	0. 4	0. 218	5. 62	3, 158	
		3	8	0. 4	0. 194	4. 64	2, 782	
		1	Torpedo.	0. 4	0. 127	41. 28	11, 935	Defective lead.
		1	Do.	0. 4	......	......	......	Lead slipped.
14	Explosive, mortar powder; ring, 5 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 35 feet; case, wooden, 1-inch pine; ignition, Smith's machine, 20 Dowse-Smith glycerine fuzes. **Effects**: Boat drifted, dragging ring on bottom; reject, because case may have shifted position; the explosion was normal.	1	1	0. 4	0. 032	......	......	
		1	2	0. 4	0. 055	......	......	
		1	3	0. 4	0. 027	......	......	
		1	4	0. 4	0. 050	......	......	
		1	5	0. 4	0. 035	......	......	
		1	6	0. 4	0. 052	......	......	
		3	7	0. 4	0. 015	0 007	38	
		3	8	0. 4	0. 032	0. 019	69	
		1	Torpedo.	0. 4	0. 137	17. 05	6, 620	
		1	Do.	0. 4	0. 185	26. 43	8, 868	
15	Explosive, mortar powder; ring, 5 foot; charge, 150 pounds; submergence, 31 feet; depth of water, 80 feet; case, wooden, 1-inch pine; ignition, Smith's machine, 30 Dowse-Smith fuzes (glycerine). **Effects**: Buoy thrown 30 or 40 feet upward with jet; gauge lost by parting of rawhide rope.	1	1	0. 4	0. 170	23. 32	8, 157	
		1	2	0. 4	0. 156	20. 61	7, 512	
		1	3	0. 4	0. 251	43. 34	12, 331	
		1	4	0. 4	0. 168	22. 93	8, 066	
		1	5	0. 4	0. 207	31. 45	9. 958	
		1	6	0. 4	0. 162	21. 79	7, 795	
		3	7	0. 4	0. 083	0. 066	162	
		3	8	0. 4	0. 102	0. 085	194	
		1	Torpedo.	0. 4	0. 224	35. 87	10, 869	
		1	Do.	0. 4	.....	......	......	Gauge lost.
16	Explosive, O. P. Co. compound; ring, 5 foot; charge, 18 pounds; submergence, 31 feet; depth of water, 72 feet; case, wooden, 12-inch cube of 1-inch pine; ignition, Smith's battery, 5 Dowse-Smith glycerine fuzes. **Effects**: Charge in bag bedded in sawdust; the two torpedo gauges were so upset by shock that it was impossible to open them; jet 20 to 30 feet high.	1	1	0. 4	0. 189	73. 74	17, 576	
		1	2	0. 4	0. 200	80. 46	18, 625	
		1	3	0. 4	0. 183	70. 38	17, 035	
		1	4	0. 4	0. 201	81. 13	18, 729	
		1	5	0. 4	0. 186	72. 08	17, 309	
		1	6	0. 4	0. 208	85. 74	19, 430	
		3	7	0. 4	0. 134	2. 65	1, 915	
		3	8	0. 4	0. 124	2. 37	1, 774	
17	Explosive, O. P. Co. compound and mortar powder; ring, 5 foot; charge, 18+18 pounds; submergence, 31 feet; depth of water, 100 feet; case, wooden, 12-inch cube of 1-inch pine; ignition, Smith's battery, 10 Dowse-Smith glycerine fuzes **Effects**: Compound caked; broke attachment-ring of buoy, letting ring sink; recovered by grappling.	1	1	0. 4	0. 181	69. 24	16, 850	
		1	2	0. 4	0. 219	93. 47	20, 582	
		1	3	0. 4	0. 193	76. 05	17, 938	
		1	4	0. 4	0. 215	90. 55	20. 150	
		1	5	0. 4	0. 177	66. 95	16, 477	
		1	6	0. 4	0. 219	93. 47	20, 582	
		3	7	0. 4	0. 104	1. 86	1, 510	
		3	8	0. 4	0. 073	1. 16	1, 103	
		1	Torpedo.	0. 4	0. 159	57. 35	14, 862	
		1	Do.	0. 4	.....	......	......	Lead defective.

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
18	Explosive, mortar powder; ring, 5 foot; charge, 50 pounds; submergence, 31 feet; depth of water, 70 feet; case, wooden, 1-inch pine; ignition, Smith's machine, 10 Dowse-Smith glycerine fuzes. Effects: Normal.	1	1	0.4	0.053	4.78	2,835	
		1	2	0.4	0.044	3.76	2,416	
		1	3	0.4	0.047	4.10	2,558	
		1	4	0.4	0.048	4.21	2,606	
		1	5	0.4	0.037	3.05	2,102	
		1	6	0.4	0.040	3 36	2,242	
		3	7	0.4	0.019	0.009	44	
		3	8	0.4	0.022	0.012	50	
		1	Torpedo.	0.4	0.131	15.93	6,325	
		1	Do.	0.4	0.115	13.23	5,590	
19	Explosive, mortar powder; ring, 5 foot; charge, 100 pounds; submergence, 31 feet; depth of water, 65 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 10 Dowse-Smith glycerine fuzes. Effects: A lateral jet containing fragments of case fell around the boat, distant 100 feet from torpedo—very unusual.	1	1	0.4	0.059	5.47	3,103	
		1	2	0.4	0.077	7.70	3,896	
		1	3	0.4	0.095	10.15	4,684	
		1	4	0.4	0.071	6.93	3,632	
		1	5	0.4	0.086	8.90	4,288	
		1	6	0.4	0.099	10.76	4,871	
		3	7	0.4	0.039	0.024	83	
		3	8	0.4	0.057	0.040	115	
		1	Torpedo.	0.4	0.214	33.21	10,325	
		1	Do.	0.4	0.240	40.23	11,732	
20	Explosive, O. P. Co. compound: ring, 5 foot; charge, 18 pounds; submergence, 31 feet; depth of water, 60 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 5 Dowse-Smith glycerine fuzes. Effects: Compound caked and discolored; case pulverized.	1	1	0.4	0.126	40.85	11,853	
		1	2	0.4	0.149	51.34	13,949	
		1	3	0.4	0.128	41.70	12,018	
		1	4	0.4	0.126	40.85	11,853	
		1	5	0.4	0.125	40.42	11,770	
		1	6	0.4	0.129	42.13	12,100	
		3	7	0.4	0.096	1.67	1,408	
		3	8	0.4	0.056	0.82	874	
21	Explosive, mortar powder; ring, 5 foot; charge, 50 pounds; submergence, 20 feet; depth of water, 50 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 10 Dowse-Smith glycerine fuzes. Effects: Broke shackle at buoy, and let ring fall to bottom.	1	1	0.4	0.015	1.01	1,006	
		1	2	0.4	0.025	1.89	1,528	
		1	3	0.4	0.022	1.61	1,368	
		1	4	0.4	0.029	2.27	1,722	
		1	5	0.4	0.019	1.34	1,211	
		1	6	0.4	0.028	2.17	1,674	
		3	7	0.4	0.012	0.006	33	
		1	Torpedo.	0.4	0.122	14.42	5,918	
		1	Do.	0.4	0.095	10.15	4,684	
22	Explosive, mortar powder; ring, 5 foot; charge, 150 pounds; submergence, 31 feet; depth of water, 55 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 20 Dowse-Smith glycerine fuzes. Effects: Broke bolt-head at buoy and let ring fall to bottom; broke raw-hide rope and lost a torpedo gauge.	1	1	0.4	0.139	17.40	6,709	
		1	2	0.4	0.158	21.01	7,609	
		1	3	0.4	0.156	20.61	7,512	
		1	4	0.4	0.193	28.11	9,237	
		1	5	0.4	0.180	25.37	8,628	
		1	6	0.4	0.215	33.47	10,380	
		3	7	0.4	0.090	0.072	173	
		3	8	0.4	0.103	0.086	195	
		1	Torpedo.	0.4	0.255	44.52	12,555	
		1	Do.	0.4	.....	......	......	Gauge lost.
23	Explosive, O. P. Co. compound; ring, 5 foot: charge, 18 pounds; submergence, 31 feet; depth of water, 58 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 5 Dowse-Smith glycerine fuzes. Effects: Compound badly caked; jet tinged with mud.	1	1	0.4	0.128	41.70	12,018	
		1	2	0.4	0.136	45.66	12,764	
		1	3	0.4	0.137	46.13	12,851	
		1	4	0.4	0.145	50.12	13,587	
		1	5	0.4	0.164	59.92	15,303	
		1	6	0.4	0.156	55.70	14,575	
		3	7	0.4	0.066	1.03	1,018	
		3	8	0.4	0.056	0.82	874	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
24	Explosive, mortar powder; ring, 5 foot; charge, 50 pounds; submergence, 68 feet; depth of water, 110 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 10 Dowse-Smith glycerine fuzes. Effects: Windy and rough; buoy rose its length and sunk back and reappeared before water began to bubble; lost hold of lowering rope and had to raise ring by wire buoy-rope, a job of two hours.	1	1	0.4	0.057	5.24	3,012	
		1	2	0.4	0.062	5.83	3,238	
		1	3	0.4	0.065	6.20	3,373	
		1	4	0.4	0.087	9.04	4,332	
		1	5	0.4	0.057	5.24	3,012	
		1	6	0.4	0.086	8.90	4,288	
		3	7	0.4	0.003	0.001	13	
		3	8	...	.....	......	......	None used.
		3	9	0.4	0.003	0.001	13	
		3	10	0.4	0.004	0.002	15	
		3	11	0.4	0.065	0.047	131	
		1	Torpedo.	0.4	0.100	10.92	4,918	
25	Explosive, mortar powder; ring, 5 foot; charge, 100 pounds; submergence, 68 feet; depth of water, 100 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 20 Dowse-Smith glycerine fuzes. Effects: Buoy rose its length above a dome of water about 10 feet high; fragments of case compressed ½ of an inch.	1	1	0.4	0.108	12.11	5,270	
		1	2	0.4	0.103	11.35	5,047	
		1	3	0.4	0.129	15.57	6,231	
		1	4	0.4	0.158	21.01	7,609	
		1	5	0.4	0.119	13.90	5,775	
		1	6	0.4	0.155	20.41	7,463	
		3	7	0.4	0.003	0.001	13	
		3	8	...	.....	......	......	None used.
		3	9	0.4	0.040	0.025	85	
		3	10	0.4	0.038	0.023	81	
		3	11	0.4	0.012	0.006	33	
		1	Torpedo.	0.4	0.189	27.25	9,050	
26	Explosive, mortar powder; ring, 5 foot; charge, 100 pounds; submergence, 68 feet; depth of water, 100 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 20 Dowse-Smith glycerine fuzes. Effects: Similar to last.	1	1	0.4	0.087	9.04	4,332	
		1	2	0.4	0.099	10.76	4,871	
		1	3	0.4	0.103	11.35	5,047	
		1	4	0.4	0.127	15.26	6,148	
		1	5	0.4	0.124	14.67	6,015	
		1	6	0.4	0.122	14.42	5,918	
		3	7	0.4	0.040	0.025	85	
		3	8	....	.....	......	......	None used.
		3	9	0.4	0.027	0.015	59	
		3	10	0.4	0.010	0.005	29	
		3	11	0.4	0.049	0.032	102	
27	Explosive, mortar powder; ring, 5 foot; charge, 100 pounds; submergence, 33 feet; depth of water, 71 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 20 Dowse-Smith glycerine fuzes. Effects: Explosion normal; began to use ponton raft (July 6, 1871).	1	1	0.4	0.112	12.75	5,453	
		1	2	0.4	0.130	15.73	6,273	
		1	3	0.4	0.130	15.73	6,273	
		1	4	0.4	0.138	17.23	6,664	
		1	5	0.4	0.140	17.57	6,753	
		1	6	0.4	0.155	20.41	7,463	
		3	7	0.4	0.064	0.046	129	
		3	8	0.4	0.051	0.034	106	
		1	Torpedo.	0.4	0.145	18.54	7,000	
28	Explosive, mortar powder; ring, 5 foot; charge, 50 pounds; submergence, 33 feet; depth of water, 75 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 10 Dowse-Smith glycerine fuzes. Effects: Explosion normal.	1	1	0.4	0.055	5.00	2,922	
		1	2	0.4	0.064	6.08	3,328	
		1	3	0.4	0.056	5.12	2,967	
		1	4	0.4	0.055	5.00	2,922	
		1	5	0.4	0.046	3.98	2,509	
		1	6	0.4	0.066	6.32	3,416	
		3	7	0.4	0.071	0.053	141	
		3	8	0.4	0.025	0.014	57	
		1	Torpedo.	0.4	0.126	15.11	6,106	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
29	Explosive, mortar powder; ring, 5 foot; charge, 50 pounds; submergence, 21 feet; depth of water, 110 feet; case, wooden, 2-inch pine; ignition, Smith's machine, 10 Dowse-Smith glycerine fuzes. Effects: Buoy rose 50 feet in air, bolt having parted and let ring down; wire rope nearly cut off.	1	1	0.4	0.047	4.10	2,558	
		1	2	0.4	0.055	5.00	2,922	
		1	3	0.4	0.060	5.59	3,148	
		1	4	0.4	0.064	6.08	3,328	
		1	5	0.4	0.049	4.33	2,655	
		1	6	0.4	0.049	4.33	2,655	
		3	7	0.4	0.067	0.49	134	
		3	8	...	.....	......	......	None used.
		1	Torpedo.	0.4	0.124	14.67	6,015	
30	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 33 feet; depth of water, 90 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.103	11.35	5,047	
		1	2	0.4	0.102	11.21	5,004	
		1	3	0.4	0.121	14.24	5,870	
		1	4	0.4	0.118	13.73	5,729	
		1	5	0.4	0.155	20.41	7,463	
		1	6	0.4	0.161	21.60	7,751	
		3	7	0.4	0.020	0.005	28	
		3	8	0.4	0.033	0.010	46	
		1	Torpedo.	0.4	0.162	21.79	7,795	
31	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 33 feet; depth of water, 86 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 7 Dowse-Smith glycerine fuzes. Effects: Buoy shackle-bolt broke, letting ring down; piece of rubber cap blown under strand of wire lowering rope so it could not be removed.	1	1	0.4	0.116	13.40	5,636	
		1	2	0.4	0.108	12.11	5,270	
		1	3	0.4	0.093	9.87	4,598	
		1	4	0.4	0.146	18.72	7,046	
		1	5	0.4	0.083	8.50	4,162	
		1	6	0.4	0.098	10.61	4,824	
		3	7	0.4	0.057	0.040	115	
		3	8	0.4	0.039	0.024	83	
		1	Torpedo.	0.4	0.091	9.50	4,510	
32	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 33 feet; depth of water, 95 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Normal.	1	1	0.4	0.134	16.51	6,479	
		1	2	0.4	0.115	13.23	5,500	
		1	3	0.4	0.139	17.40	6,709	
		1	4	0.4	0.170	23.32	8,157	
		1	5	0.4	0.162	21.79	7,795	
		1	6	0.4	0.164	22.16	7,884	
		3	7	0.4	0.089	0.071	172	
		3	8	0.4	0.074	0.056	146	
		1	Torpedo.	0.4	0.151	19.65	7,276	
33	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 33 feet; depth of water, 85 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 25 Dowse-Smith glycerine fuzes. Effects: Normal.	1	1	0.4	0.195	28.54	9,332	
		1	2	0.4	0.212	32.68	10,216	
		1	3	0.4	0.206	31.22	9,808	
		1	4	0.4	0.225	36.13	10,922	
		1	5	0.4	0.238	39.67	11,623	
		1	6	0.4	0.259	45.74	12,783	
		3	7	0.4	0.096	0.079	184	
		3	8	0.4	0.103	0.086	195	
34	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 33 feet; depth of water, 95 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Fragments of case rather large.	1	1	0.4	.....	......	......	Tipped over.
		1	2	0.4	0.045	3.86	2,460	
		1	3	0.4	0.056	5.12	2,967	
		1	4	0.4	0.062	5.83	3,238	
		1	5	0.4	0.067	6.44	3,460	
		1	6	0.4	0.071	6.93	3,632	
		3	7	0.4	0.005	0.002	16	
		3	8	0.4	0.030	0.017	65	
		1	Torpedo.	0.4	0.127	15.26	6,148	

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Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
35	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 33 feet; depth of water, 95 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Cable gauge-bolts broke, letting ring down; buoy fell on side, from jet.	1	1	0.4	0.170	23.32	8,157	
		1	2	0.4	0.175	24.32	8,388	
		1	3	0.4	0.129	15.57	6,231	
		1	4	0.4	0.191	27.68	9,142	
		1	5	0.4	0.188	27.05	9,004	
		1	6	0.4	0.185	26.43	8,868	
		3	7	0.4	0.047	0.031	99	
		3	8	0.4	.....	......	......	Lost gauge.
		1	Torpedo.	0.4	0.105	11.64	5,133	
36	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 33 feet; depth of water, 95 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 1 Dowse-Smith fuze (powder). Effects: Spray fell in boat 100 feet from torpedo.	1	1	0.4	0.119	13.90	5,775	
		1	2	0.4	0.116	13.40	5,636	
		1	3	0.4	0.166	22.54	7,975	
		1	4	0.4	0.124	14.67	6,015	
		1	5	0.4	0.136	16.88	6,575	
		1	6	0.4	0.136	16.88	6,575	
		3	7	0.4	0.035	0.021	75	
		3	8	0.4	.....	......	......	Lead slipped.
		1	Torpedo.	0.4	0.196	28.78	9,384	
37	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 33 feet; depth of water, 90 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 25 Dowse-Smith glycerine fuzes. Effects: Normal explosion.	1	1	0.4	0.167	22.74	8,020	
		1	2	0.4	0.153	20.03	7,369	
		1	3	0.4	0.148	19.09	7,138	
		1	4	0.4	0.109	12.27	5,315	
		1	5	0.4	0.113	12.81	5,498	
		1	6	0.4	0.129	15.57	6,231	
		3	7	0.4	0.081	0.063	158	
		3	8	0.4	0.059	0.042	118	
		1	Torpedo.	0.4	0.049	4.33	2,655	
38	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 33 feet; depth of water, 101 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Bale of wire rope head broke, letting ring down; cable gauge fell on No. 2.	1	1	0.4	0.135	16.71	6,531	
		1	2	0.4	. .	......	......	Bent by blow.
		1	3	0.4	0.136	16.88	6,575	
		1	4	0.4	0.144	18.35	6,951	
		1	5	0.4	0.162	21.79	7,795	
		1	6	0.4	0.140	17.57	6,753	
		3	7	0.4	0.060	0.043	120	
		3	8	...	.....	......	......	None used.
		1	Torpedo.	0.4	0.188	27.05	9,004	
39	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 33 feet; depth of water, 105 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 1 Dowse-Smith fuze (powder). Effects: Normal.	1	1	0.4	0.122	14.42	5,918	
		1	2	0.4	0.124	14.67	6,015	
		1	3	0.4	0.152	19.84	7,323	
		1	4	0.4	0.118	13.73	5,729	
		1	5	0.4	0.151	19.65	7,276	
		1	6	0.4	0.147	18.90	7,092	
		3	7	0.4	0.081	0.063	158	
		3	8	0.4	0.088	0.070	170	
		1	Torpedo.	0.4	0.085	8.76	4,246	
40	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 33 feet; depth of water, 105 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 7 Dowse-Smith glycerine fuzes. Effects: Normal.	1	1	0.4	0.140	17.57	6,753	
		1	2	0.4	0.177	24.74	8,484	
		1	3	0.4	0.158	21.01	7,609	
		1	4	0.4	0.172	23.72	8,249	
		1	5	0.4	0.196	28.78	9,384	
		1	6	0.4	0.195	28.54	9,332	
		3	7	0.4	0.057	0.040	115	
		3	8	0.4	0.105	0.088	198	
		1	Torpedo.	0.4	0.113	12.81	5,498	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
41	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 6 feet; depth of water, 19 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 10-Dowse-Smith glycerine fuzes. Effects: The ring was supported by two barrels; they were crushed by the explosion, and the ring was lost; jet over 300 feet high.	1	1	0.4	.....	......	......	Ring lost.
		1	2	0.4	.....	......	......	
		1	3	0.4	.....	......	......	
		1	4	0.4	.....	......	......	
		1	5	0.4	.....	......	......	
		1	6	0.4	.....	......	......	
		1	Torpedo.	0.4	0.141	17.76	6,802	
42	Explosive, mortar powder; ring, 3 foot; charge, 100 pounds; submergence, 32 feet; depth of water, 106 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 2 Dowse-Smith fuzes (powder), and 12 feet Gomez fuze. Effects: Normal.	1	1	0.4	0.165	22.35	7,929	
		1	2	0.4	0.151	19.65	7,276	
		1	3	....	.....	......	......	Lead accidentally omitted.
		1	4	0.4	0.169	23.13	8,111	
		1	5	0.4	0.231	37.74	11,244	
		1	6	0.4	0.221	35.08	10,708	
		3	7	0.4	0.007	0.003	21	
		3	8	0.4	0.042	0.014	57	
		1	Torpedo.	0.4	0.108	12.11	5,270	
43	Explosive, O. P. Co. compound; ring, 3 foot; charge, 6 pounds; submergence, 32 feet; depth of water, 103 feet; case, wooden, 12-inch cube, 1-inch pine; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Dome of water 10 feet high.	1	1	0.4	0.074	19.75	7,300	
		1	2	0.4	9.069	18.08	6,884	
		1	3	0.4	0.059	14.82	6,028	
		1	4	0.4	0.052	12.62	5,395	
		1	5	0.4	0.067	17.41	6,711	
		1	6	0.4	0.073	19.42	7,218	
		3	7	0.4	0.015	0.17	307	
		3	8	0.4	0.029	0.34	484	
44	Explosive, O. P. Co. compound; ring, 3 foot; charge, 12 pounds; submergence, 32 feet; depth of water, 100 feet; case, 12-inch cube, 1-inch pine; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Dome of water, 15 feet high.	1	1	0.4	0.194	76.64	18,029	
		1	2	0.4	0.204	83.16	19,041	
		1	3	0.4	0.194	76.64	18,029	
		1	4	0.4	0.191	74.88	17,756	
		1	5	0.4	0.170	63.10	15,837	
		1	6	0.4	0.191	74.88	17,756	
		3	7	0.4	0.074	1.18	1,116	
		3	8	0.4	0.030	0.35	496	
45	Explosive, mortar powder; ring, 3 foot; charge, 50 pounds; submergence, 32 feet; depth of water, 94 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 10 Dowse-Smith fuzes and 12 feet of Gomez fuse. Effects: Torpedo-gauge attached by 3 braided leading wires and raw-hide rope; both held.	1	1	0.4	0.105	11.64	5,133	
		1	2	0.4	0.102	11.21	5,004	
		1	3	0.4	0.100	10.92	4,918	
		1	4	0.4	0.084	8.63	4,204	
		1	5	0.4	0.085	8.76	4,246	
		1	6	0.4	0.075	7.42	3,802	
		3	7	0.4	0.014	0.007	36	
		3	8	0.4	0.023	0.012	53	
		2	Torpedo.	0.5	0.286	4.44	2,702	
46	Explosive, mortar powder; ring, 3 foot; charge, 50 pounds; submergence, 32 feet; depth of water, 95 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Ring seen in the jet about 10 feet above sea-level; braided wires on torpedo-gauge broke; raw-hide held.	1	1	0.4	0.079	7.98	3,990	
		1	2	0.4	0.092	9.73	4,554	
		1	3	0.4	0.095	10.15	4,684	
		1	4	0.4	0.181	27.58	8,676	
		1	5	0.4	0.134	16.51	6,479	
		1	6	0.4	0.106	11.80	5,179	
		3	7	0.4	0.014	0.007	36	
		3	8	0.4	0.021	0.011	48	
		2	Torpedo.	0.5	0.201	2.69	1,933	

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Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
47	**Explosive, mortar powder; ring, 3 foot; charge, 100 pounds; submergence, 32 feet; depth of water, 95 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Fine explosion.**	1	1	0.4	0.187	26.84	8,959	
		1	2	0.4	0.157	20.81	7,560	
		1	3	0.4	0.293	56.32	14,681	
		1	4	0.4	0.268	48.50	13,291	
		1	5	0.4	0.237	39.40	11,569	
		1	6	0.4	0.245	41.65	12,007	
		3	7	-0.4	0.067	0.025	86	
		3	8	0.4	0.087	0.036	108	
		2	Torpedo.	0.5	0.473	12.62	4,758	
48	**Explosive, O. P. Co. compound; ring 3 foot; charge, 18 pounds; submergence, 32 feet; depth of water, 85 feet; case, wooden cube, 12 inches, 1-inch pine; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Case literally broken to small match wood; dome 15 feet high.**	1	1	0.4	0.237	106.6	22,465	
		1	2	0.4	0.236	105.8	22,360	
		1	3	0.4	0.237	106.6	22,465	
		1	4	0.4	0.227	99.2	21,418	
		1	5	0.4	0.255	120.5	24,380	
		1	6	0.4	0.266	129.6	25,598	
		3	7	0.4	0.121	2.29	1,738	
		3	8	0.4	0.071	1.12	1,078	
49	**Explosive, mortar powder; ring, 3 foot; charge, 50 pounds; submergence, 32 feet; depth of water, 102 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Ring thrown into air by the jet.**	1	1	0.4	0.103	11.35	5,047	
		1	2	0.4	0.105	11.64	5,133	
		1	3	0.4	0.098	10.61	4,824	
		1	4	0.4	0.080	8.12	4,037	
		1	5	0.4	0.067	6.44	3,460	
		1	6	0.4	0.091	9.59	4,510	
		3	7	0.4	0.038	0.023	81	
		3	8	0.4	0.013	0.006	34	
		2	Torpedo.	0.5	0.344	5.89	3,258	
50	**Explosive, dynamite No. 1; ring 3 foot; charge, 6 pounds; submergence, 32 feet; depth of water, 100 feet; case, double wooden, of 1-inch pine; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Sockets forced home hard; 1 gib broken; No. 5 gauge-pin slightly upset; case pulverized; local action excessive; water rose only 5 feet.**	1	1	0.4	0.272	134.4	26,226	
		1	2	0.4	0.271	133.6	26,118	
		1	3	0.4	0.271	133.6	26,118	
		1	4	0.4	0.262	126.3	25,156	
		1	5	0.4	0.294	153.2	28,618	
		1	6	0.4	0.320	179.0	31,740	
		3	7	0.4	0.121	2.29	1,738	
		3	8	0.4	0.056	0.82	874	
51	**Explosive, mortar powder; ring, 3 foot; charge, 100 pounds; submergence, 6 feet, depth of water, 26 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Ring supported by large box with two guard ropes for raising; jet 265 feet high; box thrown in fragments above highest water; ring recovered from mud 11 feet over its top.**	1	1	0.4	0.187	26.84	8,950	
		1	2	0.4	0.223	35.61	10,815	
		1	3	0.4	0.255	44.52	12,555	
		1	4	0.4	0.250	43.05	12,275	
		1	5	0.4	0.249	42.77	12,221	
		1	6	0.4	0.288	54.72	14,403	
		1	Torpedo.	0.4	0.120	14.07	5,821	
52	**Explosive, mortar powder; ring, 3 foot; charge, 100 pounds; submergence, 32 feet; depth of water, 88 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.**	1	1	0.4	0.145	18.54	7,000	
		1	2	0.4	0.177	24.74	8,484	
		1	3	0.4	0.220	34.82	10,655	
		1	4	0.4	0.218	34.28	10,545	
		1	5	0.4	0.128	15.42	6,189	
		1	6	0.4	0.123	14.59	5,967	
		3	7	0.4	0.035	0.021	75	
		3	8	0.4	0.038	0.023	81	
		2	Torpedo.	0.5	0.427	8.54	4,175	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
53	Explosive, O. P. Co. compound; ring, 3 foot; charge, 6 pounds; submergence, 32 feet; depth of water, 88 feet; case, wooden, 12-inch cube, 1-inch pine; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Normal.	1	1	0.4	0.128	41.70	12,018	
		1	2	0.4	0.110	33.62	10,412	
		1	3	0.4	0.072	19.08	7,135	
		1	4	0.4	0.067	17.41	6,711	
		1	5	0.4	0.096	27.86	9,184	
		1	6	0.4	0.128	41.70	12,018	
		3	7	0.4	0.027	0.31	461	
		3	8	0.4	0.027	0.31	461	
54	Explosive, O. P. Co. compound; ring, 3 foot; charge, 12½ pounds; submergence, 32 feet; depth of water, 90 feet; case, wooden, 12-inch cube of 1-inch pine; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Normal.	1	1	0.4	0.240	108.8	22,780	
		1	2	0.4	0.232	102.9	21,940	
		1	3	0.4	0.259	123.8	24,820	
		1	4	0.4	0.274	136.1	26,442	
		1	5	0.4	0.251	117.3	23,948	
		1	6	0.4	0.266	129.6	25,598	
		3	7	0.4	0.097	1.69	1,422	
		3	8	0.4	0.041	0.55	669	
55	Explosive, gun-cotton; ring, 3 foot; charge, 6 pounds; submergence, 32 feet; depth of water, 90 feet; case, wooden, 12-inch cube of 1-inch pine; ignition, Smith's battery, 3 Abel fuzes. Effects: Severe local effect on iron apparatus; insignificant boiling of water.	1	1	0.4	0.241	109.60	22,789	
		1	2	0.4	0.252	118.10	24,056	
		1	3	0.4	0.224	97.04	21,106	
		1	4	0.4	0.220	94.20	20,690	
		1	5	0.4	0.197	78.52	18,322	
		1	6	0.4	0.168	62.03	15,658	
		3	7	0.4	0.070	1.10	1,065	
		3	8	0.4	0.037	0.48	608	
56	Explosive, mortar powder; ring, 3 foot; charge, 100 pounds; submergence, 6 feet; depth of water, 104 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Ring supported by 2 barrels; their fragments rose above jet, which was 275 feet high; the buoy was attached to ring by 4½-inch rope with 90 feet slack, which held.	1	1	0.4	.....	......	......	Pin jammed.
		1	2	0.4	0.131	15.93	6,325	
		1	3	0.4	0.137	17.05	6,620	
		1	4	0.4	0.110	12.43	5,361	
		1	5	0.4	0.109	12.27	5,315	
		1	6	0.4	0.156	20.61	7,512	
		2	Torpedo.	0.5	0.410	7.97	3,988	
57	Explosive, dualin; ring, 3 foot; charge, 6 pounds; submergence, 32 feet; depth of water, 104 feet; case, wooden, 12-inch cube of 1-inch pine; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Violent local action; dome 5 feet high.	1	1	0.4	0.258	123.00	24,710	
		1	2	0.4	0.204	83.16	19,041	
		1	3	0.4	0.237	106.60	22,465	
		1	4	0.4	0.258	123.00	24,710	
		1	5	0.4	0.249	115.70	23,737	
		1	6	0.4	0.238	107.30	22,570	
		3	7	0.4	0.070	1.10	1,065	
		3	8	0.4	0.042	0.57	683	
58	Explosive, mortar powder; ring, 5 foot; charge, 200 pounds; submergence, 33 feet; depth of water, 102 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Connection of wire rope to ring parted and latter was lost; hereafter guard rope always used, giving three chances to recover ring.	1	1	0.4	.....	......	......	Ring lost.
		1	2	0.4	.....	......	......	
		1	3	0.4	.....	......	......	
		1	4	0.4	.....	......	......	
		1	5	0.4	.....	......	......	
		1	6	0.4	.....	......	......	
		3	7	0.4	0.147	0.14	274	
		3	8	0.4	0.224	0.28	424	
		2	Torpedo.	0.5	0.687	......	......	Off scale.

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Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
59	Explosive, mortar powder; ring, 4 foot; charge 200 pounds; submergence, 43 feet; depth of water, 109 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Fine explosion.	1	1	0. 4	0. 329	69. 66	16, 533	
		1	2	0. 4	0. 260	46. 05	12, 840	
		1	3	0. 4	0. 260	46. 05	12, 840	
		1	4	0. 4	0. 286	54. 03	14, 283	
		1	5	0. 4	0. 239	39. 95	11, 678	
		1	6	0. 4	0. 276	50. 92	13, 729	
		3	7	0. 4	0. 136	0. 127	253	
		3	8	0. 4	0. 053	0. 036	109	
		2	Torpedo.	0. 5	0. 702	22. 79	8, 032	
60	Explosive, mortar powder; ring, 4 foot: charge 100 pounds; submergence, 33 feet; depth of water, 109 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 1 Abel powder-fuze. Effects: Normal.	1	1	0. 4	0. 166	22. 54	7, 975	
		1	2	0. 4	0. 125	14. 95	6, 064	
		1	3	0. 4	0. 147	18. 90	7, 092	
		1	4	0. 4	0. 143	18. 15	6, 901	
		1	5	0. 4	0. 116	13. 40	5, 636	
		1	6	0. 4	0. 128	15. 42	6, 189	
		3	7	0. 4	0. 057	0. 040	115	
		3	8	0. 4	0. 087	0. 070	170	
		2	Torpedo.	0. 5	0. 488	10. 81	4, 884	
61	Explosive, gun-cotton; ring, 4 foot; charge, 6 pounds; submergence, 33 feet; depth of water, 108 feet; case, double wooden cube of 1 inch pine; ignition, Smith's battery, 1 Abel detonating fuze. Effects: Normal.	1	1	0. 4	0. 163	59. 42	15, 217	
		1	2	0. 4	0. 137	46. 13	12, 851	
		1	3	0. 4	0. 165	60. 43	15, 390	
		1	4	0. 4	0. 128	41. 70	12, 018	
		1	5	0. 4	0. 128	41. 70	12, 018	
		1	6	0. 4	0. 123	39. 47	11, 584	
		3	7	0. 4	0. 017	0. 19	325	
		3	8	0. 4	0. 040	0. 53	654	
62	Explosive, dualin; ring, 4 foot; charge 6 pounds; submergence 33 feet; depth of water, 110 feet; case, double wooden of 1-inch pine; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Strong smell after explosion.	1	1	0. 4	0. 165	60. 43	15, 390	
		1	2	0. 4	0. 201	81. 13	18, 729	
		1	3	0. 4	0. 164	59. 92	15, 303	
		1	4	0. 4	0. 164	59. 92	15, 303	
		1	5	0. 4	0. 136	45. 66	12, 764	
		1	6	0. 4	0. 149	51. 34	13, 949	
		3	7	0. 4	0. 080	1. 31	1, 196	
		3	8	0. 4	0. 047	0. 66	754	
63	Explosive, gun-cotton; ring, 4 foot; charge 12 pounds; submergence, 33 feet; depth of water, 110 feet; case, double wooden of 1-inch pine; ignition, Smith's battery, 2 Abel detonating fuzes. Effects: Local damage to iron-work.	1	1	0. 4	0. 301	159. 6	29, 434	
		1	2	0. 4	0. 318	176. 9	31, 492	
		1	3	0. 4	0. 277	138. 7	26, 778	
		1	4	0. 4	0. 274	136. 1	26, 442	
		1	5	0. 4	0. 259	123. 8	24, 820	
		1	6	0. 4	0. 259	123. 8	24, 820	
		3	7	0. 4	0. 039	0. 51	639	
		3	8	0. 4	0. 078	1. 27	1, 169	
64	Explosive, O. P. Co. compound; ring, 4 foot; charge, 18 pounds; submergence, 33 feet; depth of water, 110 feet; case, wooden, 12-inch cube of 1-inch pine; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Dark scum rose to surface of water after explosion; the powder was caked.	1	1	0. 4	0. 148	51. 03	13, 859	
		1	2	0. 4	0. 147	50. 73	13, 768	
		1	3	0. 4	0. 082	22. 65	7, 999	
		1	4	0. 4	0. 125	40. 42	11, 770	
		1	5	0. 4	0. 101	29. 98	9, 640	
		1	6	0. 4	0. 092	26. 32	8, 841	
		3	7	0. 4	0. 060	0. 89	925	
		3	8	0. 4	0. 044	0. 60	713	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
65	Explosive, mortar powder; ring, 4 foot; charge, 200 pounds; submergence 43 feet; depth of water, 98 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 1 Abel powder-fuze. Effects: Lost torpedo gauge by the parting of two raw-hide ropes; ring showed a bad weld.	1	1	0.4	0.269	48.80	13,345	
		1	2	0.4	0.305	60.58	15,417	
		1	3	0.4	0.279	51.92	13,906	
		1	4	0.4	0.265	47.61	13,127	
		1	5	0.4	0.272	49.70	13,508	
		1	6	0.4	0.271	49.40	13,454	
		3	7	0.4	0.135	0.126	251	
		3	8	0.4	0.076	0.058	158	
		2	Torpedo.	0.75	.....	......	......	Lost gauge.
66	Explosive, O. P. Co. compound; ring, 4 foot, charge 2 pounds; submergence 33 feet; depth of water, 98 feet; case, wooden, 6-inch cube of 2-inch pine; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Buoy hardly moved; water boiled up in a few seconds after explosion.	1	1	0.4	0.003	0.47	604	
		1	2	0.3	0.006	0.50	630	
		1	3	0.4	0.003	0.47	604	
		1	4	0.3	0.009	0.83	883	
		1	5	0.4	0.005	0.79	855	
		1	6	0.3	0.004	0.31	458	
		3	7	0.3	0.007	0.04	121	
		3	8	0.3	0.005	0.03	96	
67	Explosive, dualin; ring, 4 foot; charge, 1 pound; submergence, 33 feet; depth of water, 95 feet; case, wooden, 6-inch cube of 2-inch pine; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.040	9.10	4,356	
		1	2	0.3	0.091	16.30	6,421	
		1	3	0.4	0.036	7.96	3,988	
		1	4	0.3	0.049	7.13	3,700	
		1	5	0.4	0.046	10.76	4,876	
		1	6	0.3	0.057	8.75	4,241	
		3	7	0.3	0.014	0.09	191	
		3	8	0.3	0.017	0.10	217	
68	Explosive, dynamite No. 1; ring, 4 foot; charge, 1 pound; submergence, 33 feet; depth of water, 95 feet; case, wooden, 6-inch cube of 2-inch pine; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Fish jumping from water at 100 yards distance.	1	1	0.4	0.032	6.88	3,617	
		1	2	0.3	0.055	8.22	4,071	
		1	3	0.4	0.028	5.85	3,240	
		1	4	0.3	0.051	7.49	3,825	
		1	5	0.4	0.040	9.10	4,356	
		1	6	0.3	0.060	9.54	4,495	
		3	7	0.3	0.013	0.08	182	
		3	8	0.3	0.014	0.09	191	
69	Explosive, gun-cotton; ring, 4 foot; charge 1 pound; submergence, 33 feet; depth of water, 95 feet; case, wooden, 6-inch cube of 2-inch pine; ignition, Smith's battery, 1 Abel detonating fuze. Effects: Boiling of water began in 15 seconds after explosion.	1	1	0.4	0.029	6.10	3,336	
		1	2	0.3	0.038	5.16	2,981	
		1	3	0.4	0.024	4.84	2,855	
		1	4	0.3	0.041	5.70	3,189	
		1	5	0.4	0.028	5.85	3,240	
		1	6	0.3	0.043	6.05	3,317	
		3	7	0.3	0.013	0.08	182	
		3	8	0.3	0.012	0.07	172	
70	Explosive, mortar powder; ring, 4 foot; charge, 50 pounds; submergence, 33 feet; depth of water, 95 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 1 Dowse-Smith powder fuze. Effects: Immense number of fish killed.	1	1	0.4	0.029	2.27	1,722	
		1	2	0.3	0.055	2.48	1,831	
		1	3	0.4	0.016	1.09	1,057	
		1	4	0.3	0.033	1.28	1,177	
		1	5	0.4	0.012	0.79	848	
		1	6	0.3	0.045	1.93	1,549	
		3	7	0.3	0.021	0.005	30	
		3	8	0.3	0.039	0.013	54	
		2	Torpedo.	0.5	0.145	1.64	1,387	

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Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
71	Explosive, mortar powder; ring, 4 foot; charge, 50 pounds; submergence, 33 feet; depth of water, 95 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 1 Abel powder fuze. Effects: Normal.	1	1	0.4	0.024	1.80	1,475	
		1	2	0.3	0.059	2.74	1,958	
		1	3	0.4	0.019	1.34	1,211	
		1	4	0.3	0.061	2.87	2,029	
		1	5	0.4	0.016	1.09	1,057	
		1	6	0.3	0.047	2.04	1,605	
		3	7	0.3	0.017	0.004	25	
		3	8	0.3	0.069	0.026	89	
		2	Torpedo.	0.5	0.179	2.27	1,725	
72	Explosive, dynamite No. 1; ring, 4 foot; charge, 6 pounds; submergence, 33 feet; depth of water, 90 feet; case, double wooden, of 1-inch pine; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Fish jumping from water as far as the eye can distinguish them.	1	1	0.4	0.170	63.10	15,837	
		1	2	0.3	0.249	73.12	17,478	
		1	3	0.4	0.158	56.80	14,766	
		1	4	0.4	0.165	60.43	15,390	
		1	5	0.4	0.141	48.04	13,208	
		1	6	0.3	0.191	47.78	13,159	
		3	7	0.3	0.166	2.31	1,748	
		3	8	0.3	0.080	0.82	876	
73	Explosive, dualin, loose; ring, 4 foot; charge, 12 pounds; submergence, 33 feet; depth of water, 90 feet; case, wooden, of 1-inch pine; ignition, Smith's battery, 3 Dowse-Smith glycerine fuzes. Effects: Ring parted in two pieces at bad weld, developed by shot No. 65; other damage to iron-work.	1	1	0.4	0.308	167.1	30,314	
		1	2	0.3	0.357	143.9	27,440	
		1	3	0.4	0.263	127.1	25,269	
		1	4	0.4	0.275	136.9	26,550	
		1	5	0.4	0.247	114.2	23,531	
		1	6	0.4	0.262	126.3	25,156	
		3	7	0.3	0.242	4.17	2,590	
		3	8	0.3	0.197	2.98	2,071	
74	Explosive, gun-cotton; ring, 3 foot; charge, 3 pounds; submergence, 32 feet; depth of water, 92 feet; case, wooden cube of 2-inch pine; ignition, Smith's battery, 1 Abel gun-cotton fuze. Effects: Normal. Began use of wire torpedo slings (September 18, 1871).	1	1	0.4	0.165	60.43	15,390	
		1	2	0.3	0.214	56.94	14,790	
		1	3	0.4	0.146	50.42	13,678	
		1	4	0.3	0.219	58.87	15,146	
		1	5	0.4	0.143	49.08	13,397	
		1	6	0.3	0.230	63.73	15,947	
		3	7	0.3	0.079	0.81	866	
		3	8	0.3	0.059	0.56	682	
75	Explosive, nitro-glycerine; ring, 3 foot; charge, 1 pound; submergence, 32 feet; depth of water, 93 feet; case, glass bottle, open; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Normal. Milky state; supplied by Marcelin & Warren.	1	1	0.4	0.139	47.06	13,026	
		1	2	0.3	0.199	50.84	13,715	
		1	3	0.4	0.122	39.00	11,491	
		1	4	0.3	0.163	37.41	11,175	
		1	5	0.4	0.122	39.00	11,491	
		1	6	0.3	0.170	39.86	11,660	
		3	7	0.3	0.105	1.19	1,122	
		3	8	0.3	0.071	0.71	795	
76	Explosive, nitro-glycerine; ring, 3 foot; charge, 2 pounds; submergence, 32 feet; depth of water, 93 feet; case, glass bottle, open; ignition, Smith's machine, 2 Mowbray fuzes. Effects: Similar to dynamite No. 1.	1	1	0.4	0.160	57.90	14,957	
		1	2	0.3	0.223	60.73	15,443	
		1	3	0.4	0.135	45.20	12,677	
		1	4	0.3	0.196	49.63	13,497	
		1	5	0.4	0.190	74.30	17,665	
		1	6	0.3	0.212	56.13	14,650	
		3	7	0.3	0.176	2.52	1,850	
		3	8	0.3	0.087	0.93	954	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
77	Explosive, nitro-glycerine; ring, 3 foot; charge, 3 pounds; submergence, 32 feet; depth of water, 93 feet; case, glass bottle, open; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Suspension strap of ring broke and lowering rope; the guard rope saved the ring.	1	1	0.4	0.200	80.46	18,625	
		1	2	0.3	0.307	104.80	22,214	
		1	3	0.4	0.214	89.84	20,044	
		1	4	0.3	0.297	98.35	21,292	
		1	5	0.4	0.181	69.24	16,850	
		1	6	0.3	0.241	69.19	16,844	
		3	7	0.3	0.210	3.29	2,210	
		3	8	0.3	0.163	2.25	1,718	
78	Explosive, dynamite No. 1; ring, 3 foot; charge, 1 pound; submergence, 32 feet; depth of water, 102 feet; case, glass bottle, sand tamped; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.210	......	......	Hammered.
		1	2	0.3	0.179	43.17	12,299	
		1	3	0.4	0.221	......	......	Hammered.
		1	4	0.3	0.203	52.46	14,005	
		1	5	0.4	0.125	40.42	11,770	
		1	6	0.3	0.157	35.26	10,743	
		3	7	0.3	0.097	1.07	1,044	
		3	8	0.3	0.064	0.61	721	
79	Explosive, dynamite No. 1; ring, 3 foot; charge, 2 pounds; submergence, 32 feet; depth of water, 102 feet; case, glass bottle, sand tamped; ignition, Smith's battery; 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.218	92.74	20,474	
		1	2	0.3	0.292	95.57	20,890	
		1	3	0.4	0.225	97.75	21,210	
		1	4	0.3	0.283	90.84	20,193	
		1	5	0.4	0.186	72.08	17,309	
		1	6	0.3	0.246	71.63	17,239	
		3	7	0.3	0.147	1.91	1,541	
		3	8	0.3	0.087	0.93	954	
80	Explosive, dynamite No. 1; ring, 3 foot; charge, 3 pounds; submergence, 32 feet; depth of water, 102 feet; case, glass bottle, closely packed; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Suspension strap showed crack.	1	1	0.4	0.333	192.2	33,384	
		1	2	0.3	0.339	128.6	25,466	
		1	3	0.4	0.312	171.3	30,790	
		1	4	0.3	0.339	128.6	25,466	
		1	5	0.4	0.270	132.8	26,010	
		1	6	0.3	0.341	130.3	25,688	
		3	7	0.3	0.157	2.13	1,656	
		3	8	0.3	0.107	1.22	1,142	
81	Explosive, gun-cotton; ring, 3 foot; charge, 1 pound; submergence, 32 feet; depth of water, 102 feet; case, wooden, 6-inch cube of 2-inch pine; ignition, Smith's battery, 1 Abel fuze. Effects: Suspension strap showed increased crack; dangerous to use longer.	1	1	0.4	0.039	8.81	4,264	
		1	2	0.3	0.057	8.75	4,241	
		1	3	0.4	0.045	10.45	4,776	
		1	4	0.3	0.052	7.67	3,887	
		1	5	0.4	0.037	8.24	4,060	
		1	6	0.3	0.057	8.75	4,241	
		3	7	0.3	0.015	0.09	201	
		3	8	0.3	0.010	0.06	153	
82	Explosive, mortar powder; ring, 3 foot; charge, 100 pounds; submergence, 33 feet; depth of water, 108 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Normal.	1	1	0.4	0.142	17.96	6,802	
		1	2	0.3	0.242	40.80	11,842	
		1	3	0.4	0.222	35.34	10,762	
		1	4	0.3	0.282	52.83	14,068	
		1	5	0.4	0.135	16.71	6,531	
		1	6	0.3	0.197	29.02	9,437	
		3	7	0.3	0.080	0.032	100	
		3	8	0.3	0.109	0.048	132	
		2	Torpedo.	0.75	0.271	23.75	8,259	

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Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
83	Explosive, gun-cotton; ring, 3 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 108 feet; case, wooden, 6-inch cube of 2-inch pine; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	1	1	0.4	0.209	86.37	19,525	
		1	2	0.3	0.284	90.36	20,269	
		1	3	0.4	0.225	97.75	21,210	
		1	4	0.3	0.247	72.13	17,319	
		1	5	0.4	0.236	105.80	22,360	
		1	6	0.3	0.276	87.04	19,629	
		3	7	0.3	0.105	1.19	1,122	
		3	8	0.3	0.078	0.79	866	
84	Explosive, mortar powder; ring, 3 foot; charge, 100 pounds; submergence, 63½ feet; depth of water, 108 feet; case, wooden, of 2-inch pine, braced; ignition, Smith's battery, 3 Dowse-Smith glycerine fuzes. Effects: Severe jar on steamboat Henry Smith, distant 100 yards.	1	1	0.4	0.129	15.57	6,231	
		1	2	0.3	0.234	19.81	7,316	
		1	3	0.4	0.202	30.24	9,700	
		1	4	0.3	0.291	28.63	9,353	
		1	5	0.4	0.144	18.35	6,951	
		1	6	0.3	0.173	12.34	5,336	
		3	7	0.3	0.046	0.016	61	
		3	8	0.3	0.057	0.020	75	
		2	Torpedo.	0.75	0.362	37.47	11,193	
85	Explosive, mortar powder; ring, 3 foot; charge, 100 pounds; submergence, 6 feet; depth of water, 108 feet; case, wooden, 1-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Ring supported by 2 barrels and connected to buoy by guard rope; fragments of barrels fell a hundred yards distant.	1	1	0.4	0.193	28.11	9,237	
		1	2	0.3	0.292	28.79	9,388	
		1	3	0.4	0.183	28.01	8,772	
		1	4	0.3	0.357	43.37	12,337	
		1	5	0.4	0.122	14.42	5,918	
		1	6	0.3	0.239	20.55	7,498	
		2	Torpedo.	0.75	0.429	50.90	13,725	
86	Experiment in air, yielding no definite result.							
87	Explosive, mortar powder; ring, 3 foot; charge, 100 pounds; submergence, 33 feet; depth of water, 100 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Torpedo-gauge lost by parting of raw-hide rope and two pieces of telegraph wire.	1	1	0.4	0.219	34.55	10,600	
		1	2	0.5	0.072	14.91	6,053	
		1	3	0.5	0.122	30.82	9,823	
		1	4	0.4	0.150	19.46	7,230	
		1	5	0.4	0.157	20.81	7,560	
		1	6	0.5	0.037	6.54	3,492	
		3	7	0.3	0.151	0.077	180	
		3	8	0.3	0.287	0.214	358	
		2	Torpedo.	0.75	.....	......	......	Lost gauge.
88	Explosive, gun-cotton; ring, 3 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 100 feet; case, wooden, 6-inch cube of 2-inch pine; ignition, Smith's battery, 1 Abel fuze. Effects: Normal. Sudden storm; fired from ponton raft, letting ring drift off to a safe distance.	1	1	0.4	0.130	42.56	12,183	
		1	2	0.5	0.169	81.19	18,737	
		1	3	0.5	0.091	33.22	10,328	
		1	4	0.4	0.115	35.82	10,857	
		1	5	0.4	0.089	25.19	8,588	
		1	6	0.5	0.183	91.61	20,306	
		3	7	0.3	0.017	0.10	217	
		3	8	0.3	0.042	0.36	502	
89	Explosive, mortar powder; ring, 3 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 110 feet; case, wooden, 6-inch cube of 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Normal.	1	1	0.4	0.156	20.61	7,512	
		1	2	0.5	0.084	18.29	6,936	
		1	3	0.5	0.063	12.57	5,402	
		1	4	0.4	0.158	21.01	7,609	
		1	5	0.4	0.104	11.50	5,090	
		1	6	0.5	0.080	17.14	6,643	
		3	7	0.3	0.131	0.062	157	
		3	8	0.3	0.328	0.274	421	
		2	Torpedo.	0.75	0.060	3.06	2,104	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
90	Explosive, gun-cotton; ring, 3 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 110 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Broke ring in an old flaw near suspension strap.	1	1	0.4	0.105	31.62	9,992	
		1	2	0.5	0.239	136.00	26,491	
		1	3	0.5	0.245	140.50	27,005	
		1	4	0.4	0.143	49.08	13,397	
		1	5	0.4	0.167	61.50	15,569	
		1	6	0.5	0.290	180.20	31,890	
		3	7	0.3	0.046	0.39	535	
		3	8	0.3	0.045	0.38	524	
91	Explosive, nitro-glycerine; ring, 4 foot; charge, 1½ pounds; submergence, 35 feet; depth of water, 92 feet; case, glass bottle, open; ignition, Smith's battery, 1 Browne fuze. Effects: Normal. From Mowbray; delivered frozen and thawed for use.	1	1	0.4	0.112	34.50	10,590	
		1	2	0.4	0.140	47.52	13,113	
		1	3	0.4	0.069	18.08	6,884	
		1	4	0.4	0.100	29.55	9,552	
		1	5	0.4	0.063	16.10	6,370	
		1	6	0.4	0.066	17.07	6,624	
		3	7	0.4	0.009	0.09	195	
		3	8	0.4	0.042	0.57	683	
92	Explosive, nitro-glycerine; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 92 feet; case, glass bottle, open; ignition, Smith's battery, 1 Browne fuze. Effects: A few bubbles in 13 seconds after explosion.	1	1	0.4	0.042	9.64	4,524	
		1	2	0.4	0.025	5.08	2,954	
		1	3	0.4	0.022	4.35	2,659	
		1	4	0.4	0.030	6.36	3,431	
		1	5	0.4	0.023	4.60	2,757	
		1	6	0.4	0.026	5.34	3,049	
		3	7	0.4	0.007	0.06	156	
		3	8	0.4	0.013	0.14	289	
93	Explosive, nitro-glycerine; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 92 feet; case, glass bottle, open; ignition, Smith's battery, 1 Browne fuze. Effects: Upward boil 9 seconds after explosion.	1	1	0.4	0.111	34.06	10,501	
		1	2	0.4	0.105	31.62	9,992	
		1	3	0.4	0.090	25.57	8,674	
		1	4	0.4	0.096	27.86	9,184	
		1	5	0.4	0.055	13.50	5,666	
		1	6	0.4	0.076	20.46	7,473	
		3	7	0.4	0.135	2.68	1,928	
		3	8	0.4	0.052	0.75	821	
94	Explosive, nitro-glycerine; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 92 feet; case, glass bottle, open; ignition, Smith's battery, 1 Browne fuze. Effects: Upward boil 5 feet high in 4 seconds after explosion.	1	1	0.4	0.168	62.03	15,658	
		1	2	0 4	0.149	51.34	13,949	
		1	3	0.4	0.110	33.62	10,412	
		1	4	0.4	0.143	49.08	13,397	
		1	5	0.4	0.097	28.28	9,276	
		1	6	0.4	0.124	39.95	11,677	
		3	7	0.4	0.177	4.04	2,536	
		3	8	0.4	0.073	1.16	1,103	
95	Explosive, nitro-glycerine; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 95 feet; case, tin can, open; ignition, Smith's battery, 1 Browne fuze. Effects: Lowering rope parted.	1	1	0.4	0.109	33.22	10,328	
		1	2	0.4	0.162	58.91	15,130	
		1	3	0.4	0.095	27.44	9,092	
		1	4	0.4	0.182	69.81	16,942	
		1	5	0.4	0.105	31.62	9,992	
		1	6	0.4	0.103	30.85	9,816	
		3	7	0.4	0.120	2.27	1,726	
		3	8	0.4	0.047	0.66	754	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
96	Explosive, dynamite No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 110 feet; case, glass bottle, sand tamped; ignition, Smith's battery, 1 Browne fuze. Effects: Normal.	1	1	0.4	0.122	39.00	11,491	
		1	2	0.4	0.117	36.71	11,036	
		1	3	0.4	0.092	26.32	8,841	
		1	4	0.4	0.085	23.69	8,244	
		1	5	0.4	0.086	24.07	8,330	
		1	6	0.4	0.073	19.42	7,218	
		3	7	0.4	0.037	0.30	451	
		3	8	0.4	0.025	0.18	319	
97	Explosive, dynamite No. 1; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 110 feet; case, glass bottle, sand tamped; ignition, Smith's battery, 1 Browne fuze. Effects: Normal.	1	1	0.4	0.169	62.57	15,748	
		1	2	0.4	0.233	......	......	Lead moved.
		1	3	0.4	0.156	55.70	14,575	
		1	4	0.4	0.166	60.96	15,479	
		1	5	0.4	0.138	46.59	12,939	
		1	6	0.4	0.141	48.04	13,208	
		3	7	0.4	0.097	1.69	1,422	
		3	8	0.4	0.061	0.91	941	
98	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 110 feet; case, glass bottle, closely packed; ignition, Smith's machine, 1 Browne fuze. Effects: Normal.	1	1	0.4	0.186	72.08	17,309	
		1	2	0.4	0.168	62.03	15,658	
		1	3	0.4	0.164	59.92	15,303	
		1	4	0.4	0.185	71.52	17,220	
		1	5	0.4	0.156	55.70	14,575	
		1	6	0.4	0.179	68.10	16,664	
		3	7	0.4	0.096	1.67	1,408	
		3	8	0.4	0.039	0.51	639	
99	Explosive, dynamite No. 1; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 110 feet; case, tin can, sand tamped; ignition, Smith's battery, 1 Browne fuze. Effects: Normal.	1	1	0.4	0.222	95.62	20,808	
		1	2	0.4	0.248	115.00	23,634	
		1	3	0.4	0.237	106.60	22,465	
		1	4	0.4	0.227	99.21	21,418	
		1	5	0.4	0.201	81.13	18,729	
		1	6	0.4	0.185	71.52	17,220	
		3	7	0.4	0.155	3.29	2,210	
		3	8	0.4	0.074	1.18	1,116	
100	Explosive, gun-cotton; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 110 feet; case, wooden, 6-inch cube of 2-inch pine; sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Hemispherical dome 3 or 4 feet high.	1	1	0.4	0.092	26.32	8,841	
		1	2	0.3	0.150	32.87	10,255	
		1	3	0.3	0.147	31.86	10,043	
		1	4	0.4	0.105	31.62	9,992	
		1	5	0.4	0.064	16.42	6,453	
		1	6	0.3	0.085	14.81	6,027	
		3	7	0.3	0.040	0.34	487	
		3	8	0.3	0.061	0.59	701	
101	Explosive, gun-cotton; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 110 feet; case, wooden, 6-inch cube 2 inches thick; sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	1	1	0.4	0.118	37.16	11,126	
		1	2	0.5	0.110	43.28	12,320	
		1	3	0.5	0.123	50.86	13,716	
		1	4	0.4	0.132	43.62	12,381	
		1	5	0.4	0.099	29.13	9,460	
		1	6	0.5	0.078	27.04	9,002	
		3	7	0.3	0.091	0.99	994	
		3	8	0.3	0.080	0.82	876	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
102	Explosive, gun-cotton; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 110 feet; case, wooden, 6-inch cube, 2-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	1	1	0.4	0.138	46.59	12,989	
		1	2	0.6	0.143	113.00	23,857	
		1	3	0.6	0.088	57.81	14,941	
		1	4	0.4	0.120	38.05	11,305	
		1	5	0.4	0.104	31.29	9,904	
		1	6	0.6	0.053	29.45	9,528	
		3	7	0.3	0.064	0.61	721	
		3	8	0.3	0.081	0.84	887	
103	Explosive, dynamite No. 1; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 110 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.155	55.15	14,480	
		1	2	0.5	0.258	150.90	28,326	
		1	3	0.5	0.173	84.14	19,190	
		1	4	0.4	0.160	57.90	14,957	
		1	5	0.4	0.155	55.15	14,480	
		1	6	0.5	0.088	31.75	10,021	
		3	7	0.3	0.153	2.05	1,610	
		3	8	0.3	0.101	1.13	1,081	
104	Explosive, dynamite, No. 1; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 110 feet; case, wooden, 6-inch cube of 2-inch pine; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.184	70.95	17,127	
		1	2	0.6	0.231	....	......	Hammered.
		1	3	0.6	0.096	64.93	16,140	
		1	4	0.4	0.183	70.38	17,035	
		1	5	0.4	0.152	53.64	14,216	
		1	6	0.6	0.120	87.80	19,740	
		3	7	0.3	0.127	1.55	1,336	
		3	8	0.3	0.103	1.16	1,102	
105	Explosive, mortar powder; ring, 4 foot; charge, 200 pounds; submergence, 45 feet; depth of water, 98 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 2 Dowse-Smith powder fuzes and 12 feet of Gomez fuze. Effects: Buoy, ring, guard rope, and all, thrown high in air, say 25 feet in the jet.	1	1	0.4	0.185	26.43	8,868	
		1	2	0.5	0.118	29.35	9,507	
		1	3	0.5	0.208	68.19	16,679	
		1	4	0.4	0.252	43.64	12,387	
		1	5	0.4	0.262	46.67	12,955	
		1	6	0.5	0.175	52.52	14,017	
		3	7	0.3	0.055	0.019	71	
		3	8	0.3	0.112	0.050	134	
		2	Torpedo.	0.75	0.226	18.29	6,937	
106	Explosive, gun-cotton; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 98 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Dome 6 to 7 feet high.	1	1	0.4	0.197	78.52	18,322	
		1	2	0.5	0.227	127.10	25,258	
		1	3	0.5	0.175	85.64	19,420	
		1	4	0.4	0.170	63.10	15,837	
		1	5	0.4	0.179	68.10	16,664	
		1	6	0.5	0.102	38.95	11,484	
		3	7	0.3	0.105	1.19	1,122	
		3	8	0.3	0.079	0.81	866	
107	Explosive, gun-cotton; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 98 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's machine, 1 Abel fuze. Effects: A boiling yellow cascade 6 feet high.	1	1	0.4	0.178	67.52	16,570	
		1	2	0.6	0.142	111.80	23,198	
		1	3	0.6	0.116	83.83	19,134	
		1	4	0.4	0.162	58.91	15,130	
		1	5	0.4	0.143	49.08	13,397	
		1	6	0.6	0.068	41.02	11,882	
		3	7	0.3	0.089	0.96	975	
		3	8	0.3	0.090	0.98	986	

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Details of experiments with the Rings—Continued.

Original number.	Details of experiments.	Gauge.		Lead-cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
108	Explosive, mortar powder; ring, 4 foot; charge, 200 pounds; submergence, 45 feet; depth of water, 98 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Shock felt strongly on land, over half a mile away.	1	1	0.4	0.260	46.05	12,840	
		1	2	0.6	0.125	73.74	17,573	
		1	3	0.6	0.044	18.45	6,975	
		1	4	0.4	0.222	35.34	10,762	
		1	5	0.4	0.181	27.58	8,676	
		1	6	0.6	0.047	20.03	7,369	
		3	7	0.3	0.163	0.086	195	
		3	8	0.3	0.185	0.105	223	
		2	Torpedo.	0.75	0.177	12.93	5,505	
109	Explosive, mortar powder; ring, 4 foot; charge, 150 pounds; submergence, 35 feet; depth of water, 98 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Buoy 30 to 40 feet in air; lost torpedo gauge by parting of rawhide rope and telegraph wire.	1	1	0.4	0.161	21.60	7,751	
		1	2	0.5	0.110	26.55	8,892	
		1	3	0.5	0.160	45.97	12,823	
		1	4	0.4	0.272	......	......	Double pin mark.
		1	5	0.4	0.218	34.28	10,545	
		1	6	0.5	0.101	23.55	8,210	
		3	7	0.3	0.141	0.069	167	
		3	8	0.3	0.249	0.168	304	
		2	Torpedo.	0.75	......	......	......	Lost gauge.
110	Explosive, mortar powder; ring, 4 foot; charge, 150 pounds; submergence, 35 feet; depth of water, 98 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 2 Dowse-Smith powder fuzes and 12 feet Gomez fuze. Effects: Buoy tossed violently in jet; connections saved by buffer newly applied.	1	1	0.4	0.199	29.50	9,542	
		1	2	0.6	0.031	11.66	5,133	
		1	3	0.6	0.087	45.14	12,623	
		1	4	0.4	0.247	42.21	12,114	
		1	5	0.4	0.140	17.57	6,753	
		1	6	0.6	0.060	27.53	9,112	
		3	7	0.3	0.069	0.026	89	
		3	8	0.3	0.275	0.199	341	
		2	Torpedo.	0.75	0.290	26.32	8,842	
111	Explosive, mammoth powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 98 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: very slight. First use of a 10-foot length of wire rope on torpedo gauges—the plan hereafter adopted to secure them.	1	1	0.4	0.008	0.50	616	
		1	2	0.4	0.010	0.64	742	
		1	3	0.4	0.007	0.42	554	
		1	4	0.4	0.013	0.86	900	
		1	5	0.4	0.010	0.64	742	
		1	6	0.4	0.013	0.86	900	
		3	7	0.3	0.009	0.002	17	
		3	8	0.3	0.003	0.001	8	
		1	Torpedo.	0.6	0.000	......	......	
112	Explosive, cannon powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 98 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Jet 30 feet high.	1	1	0.4	0.010	0.64	742	
		1	2	0.4	0.011	0.71	795	
		1	3	0.4	0.018	1.26	1,160	
		1	4	0.4	0.013	0.86	900	
		1	5	0.4	0.014	0.94	953	
		1	6	0.4	0.010	0.64	742	
		3	7	0.3	0.015	0.003	23	
		3	8	0.3	0.017	0.004	25	
		2	Torpedo.	0.75	0.001	0.016	62	
113	Explosive, mammoth powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 98 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 1 Abel powder fuze. Effects: Jet 10 feet high, darkened by powder; smoke hung over place; box in large fragments.	1	1	0.3	0.009	0.24	389	
		1	2	0.3	0.005	0.12	243	
		1	3	0.3	0.002	0.05	132	
		1	4	0.3	0.005	0.12	243	
		1	5	0.3	0.008	0.21	353	
		1	6	0.3	0.013	0.39	529	
		3	7	0.3	0.004	0.001	10	
		3	8	0.3	0.004	0.001	10	
		2	Torpedo.	0.75	0.003	0.070	156	

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Details of experiments with the Rings—Continued.

Original number.	Details of experiments.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
114	Explosive, cannon powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 98 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 1 Abel fuze. Effects: Jet 30 to 40 feet; buoy struck ring near gauge No. 2.	1	1	0. 3	0. 022	0. 78	842	
		1	2	0. 3	0. 031	1. 18	1, 115	
		1	3	0. 3	0. 016	0. 51	638	
		1	4	0. 3	0. 025	0. 92	945	
		1	5	0. 3	0. 014	0. 43	567	
		1	6	0. 3	0. 013	0. 39	529	
		3	7	0. 3	0. 016	0. 004	24	
		3	8	0. 3	0. 023	0. 006	33	
		1	Torpedo.	0. 6	0. 000	......	......	No shortening.
115	Explosive, gun-cotton; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 98 feet; case, wooden, 6-inch cube, of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Case reduced to sawdust.	1	1	0. 4	0. 152	53. 64	14, 216	
		1	2	0. 4	0. 152	53. 64	14, 216	
		1	3	0. 4	0. 146	50. 42	13, 678	
		1	4	0. 4	0. 155	55. 15	14, 480	
		1	5	0. 4	0. 150	52. 64	14, 040	
		1	6	0. 4	......	......	......	Lead tipped over.
		3	7	0. 3	0. 045	0. 38	524	
		3	8	0. 3	0. 045	0. 38	524	
116	Explosive, dualin; ring, 4 foot; charge, 6¼ pounds; submergence, 35 feet; depth of water, 98 feet; case, wooden, 6-inch cube, of 2-inch pine, full; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Locally violent.	1	1	0. 4	0. 288	148. 10	27, 974	
		1	2	0. 75	0. 108	156. 10	28, 977	
		1	3	0. 75	0. 092	127. 50	25, 319	
		1	4	0. 4	0. 270	132. 80	26, 010	
		1	5	0. 4	0. 233	103. 60	22, 045	
		1	6	0. 75	0. 067	86. 01	19, 468	
		3	7	0. 3	0. 204	3. 15	2, 146	
		3	8	0. 3	0. 134	1. 67	1, 408	
117	Explosive, dualin; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 98 feet; case, tin can, full; ignition, Smith's battery, 2 Browne fuzes. Effects: Normal.	1	1	0. 4	0. 194	76. 64	18, 029	
		1	2	0. 4	0. 250	116. 50	23, 840	
		1	3	0. 4	0. 233	103. 60	22, 045	
		1	4	0. 4	0. 225	97. 75	21, 210	
		1	5	0. 4	0. 213	89. 13	19, 938	
		1	6	0. 4	0. 215	90. 55	20, 150	
		3	7	0. 3	0. 191	2. 86	2, 016	
		3	8	0. 3	0. 131	1. 62	1, 377	
118	Explosive, mortar powder; ring, 4 foot; charge, 200 pounds; submergence, 45 feet; depth of water, 100 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 9 Browne glycerine fuzes. Effects: Normal.	1	1	0. 4	0. 382	....	......	Bent over.
		1	2	0. 75	0. 059	72. 30	17, 344	
		1	3	0. 75	0. 040	43. 40	12, 343	
		1	4	0. 4	0. 226	36. 40	10, 976	
		1	5	0. 4	0. 212	32. 68	10, 216	
		1	6	0. 75	0. 029	28. 40	9, 288	
		3	7	0. 3	0. 049	0. 017	65	
		3	8	0. 3	0. 059	0. 021	78	
		2	Torpedo.	0. 75	0. 145	9. 68	4, 540	
119	Explosive, gun-cotton; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 100 feet; case, wooden, of 1-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	1	1	0. 4	0. 059	14. 82	6, 028	
		1	2	0. 4	0. 076	20. 46	7, 473	
		1	3	0. 4	0. 050	12. 03	5, 215	
		1	4	0. 4	0. 059	14. 82	6, 028	
		1	5	0. 4	0. 068	17. 74	6, 797	
		1	6	0. 4	0. 046	10. 76	4, 864	
		3	7	0. 3	0. 019	0. 11	234	
		3	8	0. 3	0. 025	0. 18	319	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
120	Explosive, gun-cotton; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 100 feet; case, wooden, of 1-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	1	1	0.4	0.122	39.00	11,491	
		1	2	0.4	0.106	32.02	10,076	
		1	3	0.4	0.107	32.42	10,160	
		1	4	0.4	0.127	41.28	11,935	
		1	5	0.4	0.087	24.44	8,416	
		1	6	0.4	0.087	24.44	8,416	
		3	7	0.3	0.057	0.53	656	
		3	8	0.3	0.048	0.42	556	
121	Explosive, gun-cotton; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 100 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	1	1	0.4	0.110	33.62	10,412	
		1	2	0.4	0.070	18.42	6,971	
		1	3	0.4	0.082	22.65	7,999	
		1	4	0.4	0.097	28.28	9,276	
		1	5	0.4	0.066	17.07	6,624	
		1	6	0.4	0.117	36.71	11,036	
		3	7	0.3	0.017	0.10	217	
		3	8	0.3	0.044	0.37	517	
122	Explosive, dualin; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 100 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Dome 3 feet high; box reduced to sawdust.	1	1	0.4	0.193	76.05	17,938	
		1	2	0.75	0.042	46.32	12,882	
		1	3	0.75	0.051	59.53	15,209	
		1	4	0.4	0.188	73.19	17,487	
		1	5	0.4	0.157	56.25	14,671	
		1	6	0.75	0.078	103.98	22,093	
		3	7	0.3	0.157	2.13	1,656	
		3	8	0.3	0.081	0.84	887	
123	Explosive, dualin; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 100 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.178	67.52	16,570	
		1	2	0.75	0.053	62.59	15,737	
		1	3	0.75	0.059	72.33	17,347	
		1	4	0.4	0.199	79.81	18,524	
		1	5	0.4	0.160	57.90	14,957	
		1	6	0.75	0.071	92.52	20,441	
		3	7	0.3	0.183	2.68	1,928	
		3	8	0.3	0.077	0.78	845	
124	Explosive, dualin; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 100 feet; case, tin can, sand tamped; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Normal.	1	1	0.4	0.217	92.01	20,366	
		1	2	0.4	0.189	73.74	17,576	
		1	3	0.4	0.171	63.64	15,928	
		1	4	0.4	0.176	66.37	16,383	
		1	5	0.4	0.166	60.96	15,479	
		1	6	0.4	0.157	56.25	14,671	
		3	7	0.3	0.035	0.27	427	
		3	8	0.3	0.092	1.00	1,002	
125	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 6 feet; depth of water, 100 feet; case, wooden, of 1-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Supported by barrels and attached to buoy by guard rope; buoy drifted too near and was broken in two pieces by explosion.	1	1	0.4	0.094	10.01	4,641	
		1	2	0.4	0.109	12.27	5,315	
		1	3	0.4	0.078	7.84	3,943	
		1	4	0.4	0.145	18.54	7,000	
		1	5	0.4	0.095	10.15	4,684	
		1	6	0.4	0.073	7.18	3,717	
		1	Torpedo.	0.6	0.027	9.79	4,565	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
126	Explosive, mortar powder; ring, 4 foot; charge, 200 pounds; submergence, 45 feet; depth of water, 105 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 2 Dowse-Smith powder fuzes and 12 feet of Gomez fuze. Effects: Normal.	1	1	0. 4	0. 342	74. 54	17, 700	
		1	2	0. 75	0. 081	109. 00	22, 797	
		1	3	0. 75	0. 038	40. 60	11, 787	
		1	4	0. 4	0. 257	45. 13	12, 669	
		1	5	0. 4	0. 215	33. 47	10, 380	
		1	6	0. 75	0. 040	43. 40	12, 343	
		3	7	0. 3	0. 244	0. 163	298	
		3	8	0. 3	0. 190	0. 109	228	
		2	Torpedo.	0. 75	0. 266	23. 13	8, 113	
127	Explosive, mortar powder; ring, 4 foot; charge, 150 pounds; submergence, 35 feet; depth of water, 105 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 2 Dowse-Smith powder fuzes and 12 feet Gomez fuze. Effects: Normal.	1	1	0. 4	0. 151	19. 65	7, 276	
		1	2	0. 75	0. 028	27. 20	9, 010	
		1	3	0. 75	0. 009	......	......	Defective.
		1	4	0. 4	0. 182	27. 79	8, 724	
		1	5	0. 4	0. 162	21. 79	7, 795	
		1	6	0. 75	0. 012	......	......	Defective.
		3	7	0. 3	0. 059	0. 021	78	
		3	8	0. 3	0. 197	0. 115	236	
		2	Torpedo.	0. 75	0. 228	18. 51	6, 992	
128	Explosive, mortar powder; ring, 4 foot; charge, 150 pounds; submergence, 35 feet; depth of water, 105 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Normal.	1	1	0. 4	0. 144	18. 35	6, 951	
		1	2	0. 75	0. 039	42. 00	12, 065	
		1	3	0. 75	0. 015	12. 00	5, 239	
		1	4	0. 4	0. 183	28. 01	8, 772	
		1	5	0. 4	0. 176	24. 95	8, 532	
		1	6	0. 75	0. 019	16. 30	6, 416	
		3	7	0. 3	0. 194	0. 112	233	
		3	8	0. 3	0. 264	0. 186	325	
		2	Torpedo.	0. 75	0. 172	12. 43	5, 362	
129	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 105 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 1 Abel powder fuze. Effects: Jet discolored.	1	1	0. 4	0. 061	5. 71	3, 193	
		1	2	0. 75	0. 006	4. 00	2, 495	
		1	3	0. 75	0. 004	2. 56	1, 870	
		1	4	0. 4	0. 066	6. 32	3, 416	
		1	5	0. 4	0. 091	9. 59	4, 510	
		1	6	0. 75	0. 006	4. 00	2, 495	
		3	7	0. 3	0. 045	0. 015	60	
		3	8	0. 3	0. 104	0. 045	127	
		2	Torpedo.	0. 75	0. 061	3. 12	2, 133	
130	Explosive, gun-cotton; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 92 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Fired in gale; boat quite wet but battery worked well.	1	1	0. 4	0. 160	57. 90	14, 957	
		1	2	0. 75	0. 063	79. 25	18, 433	
		1	3	0. 75	0. 054	64. 12	16, 001	
		1	4	0. 4	0. 134	44. 67	12, 578	
		1	5	0. 4	0. 133	44. 14	12, 479	
		1	6	0. 75	0. 053	62. 59	15, 737	
		3	7	0. 3	0. 110	1. 27	1, 172	
		3	8	0. 3	0. 048	0. 42	556	
131	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 92 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Gale of wind; boat wet and battery in water on bottom when fired; no failure but perhaps some fuzes did not ignite.	1	1	0. 4	0. 072	7. 05	3, 675	
		1	2	0. 75	0. 011	8. 30	4, 084	
		1	3	0. 75	0. 013	10. 20	4, 662	
		1	4	0. 4	0. 074	7. 30	3, 760	
		1	5	0. 4	0. 044	3. 76	2, 416	
		1	6	0. 75	0. 003	1. 92	1, 544	
		3	7	0. 3	0. 024	0. 007	35	
		3	8	0. 3	0. 070	0. 027	90	
		2	Torpedo.	0. 75	0. 084	4. 61	2, 766	

Details of experiments with the Rings—Continued.

Original number.	Details of experiments.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
132	Explosive, dualin; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 102 feet; case, glass bottle, sand tamped; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Normal.	1	1	0.4	0.138	46.59	12,939	
		1	2	0.4	0.147	50.73	13,768	
		1	3	0.4	0.106	32.02	10,076	
		1	4	0.4	0.097	28.28	9,276	
		1	5	0.4	0.045	10.45	4,776	
		1	6	0.4	0.084	23.34	8,162	
		3	7	0.3	0.046	0.39	535	
		3	8	0.3	0.055	0.50	630	
133	Explosive, dualin; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 102 feet; case, glass bottle; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Normal.	1	1	0.4	0.167	61.50	15,569	
		1	2	0.4	0.186	72.08	17,309	
		1	3	0.4	0.140	47.52	13,113	
		1	4	0.4	0.171	63.64	15,928	
		1	5	0.4	0.128	41.70	12,018	
		1	6	0.4	0.141	48.04	13,208	
		3	7	0.3	0.102	1.14	1,091	
		3	8	0.3	0.076	0.76	835	
134	Explosive, gun-cotton; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 102 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Strong smell; large fragments of case.	1	1	0.4	0.033	7.15	3,710	
		1	2	0.4	0.034	7.41	3,803	
		1	3	0.4	0.030	6.36	3,431	
		1	4	0.4	0.031	6.62	3,524	
		1	5	0.4	0.011	1.93	1,548	
		1	6	0.4	0.025	5.08	2,954	
		3	7	0.3	0.013	0.08	182	
		3	8	0.3	0.016	0.10	209	
135	Explosive, gun-cotton; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 102 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	1	1	0.4	0.077	20.83	7,564	
		1	2	0.4	0.075	20.08	7,382	
		1	3	0.4	0.056	13.83	5,757	
		1	4	0.4	0.062	15.78	6,286	
		1	5	0.4	0.064	16.42	6,453	
		1	6	0.4	0.073	19.42	7,218	
		3	7	0.3	0.026	0.19	328	
		3	8	0.3	0.042	0.36	502	
136	Explosive, mortar powder; ring, 4 foot; charge, 50 pounds; submergence, 35 feet; depth of water, 102 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 1 Abel powder fuze. Effects: Rather large fragments of case.	1	1	0.4	0.034	2.74	1,961	
		3	2	0.75	0.184	2.56	1,868	
		3	3	0.75	0.171	2.31	1,745	
		1	4	0.4	0.043	3.66	2,373	
		1	5	0.4	0.030	2.36	1,771	
		3	6	0.75	0.180	2.47	1,828	
		3	7	0.3	0.037	0.012	51	
		3	8	0.3	0.051	0.017	67	
		2	Torpedo.	0.75	0.103	6.09	3,336	
137	Explosive, mortar powder; ring, 4 foot; charge, 50 pounds; submergence, 35 feet; depth of water, 102 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 1 Abel powder fuze. Effects: Failure; water boiled up around buoy and great fragments of box floated; evidently case leaked.	1	1	0.4	0.004	......	......	Case leaked.
		3	2	0.75	0.004	......	......	
		3	3	0.75	0.002	......	......	
		1	4	0.4	0.002	......	......	
		1	5	0.4	0.004	......	......	
		3	6	0.75	0.001	......	......	
		3	7	0.3	0.002	......	......	
		3	8	0.3	0.001	......	......	
		2	Torpedo.	0.75	0.000	......	......	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
138	Explosive, mortar powder; ring, 4 foot; charge, 50 pounds; submergence, 35 feet; depth of water, 102 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 1 Abel powder fuze. Effects: Normal.	1	1	0.4	0.008	0.50	616	
		3	2	0.75	0.104	1.17	1,110	
		3	3	0.75	0.116	1.36	1,222	
		1	4	0.4	0.020	1.42	1,262	
		1	5	0.4	0.020	1.42	1,262	
		3	6	0.75	0.202	2.91	2,040	
		3	7	0.3	0.011	0.002	17	
		3	8	0.3	0.054	0.019	71	
		2	Torpedo.	0.75	0.021	0.82	873	
139	Explosive, mortar powder; ring, 4 foot; charge, 50 pounds; submergence, 35 feet; depth of water, 102 feet; case, wooden, 2-inch pine; ignition, Smith's battery, 1 Abel powder fuze. Effects: Normal.	1	1	0.4	0 009	0.57	679	
		2	2	0.75	0.006	0.17	292	
		2	3	0.75	0.014	0.48	607	
		1	4	0.4	0.018	1.26	1,160	
		1	5	0.4	0.030	2.36	1,771	
		2	6	0.75	0.006	0.17	292	
		3	7	0.3	0.003	0.001	7	
		3	8	0.3	0.094	0.040	116	
		2	Torpedo.	0.75	0.040	1.83	1,497	
140	Explosive, mortar powder; ring, 4 foot; charge, 50 pounds; submergence, 35 feet; depth of water, 102 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 1 Abel powder fuze. Effects: Normal.	1	1	0.4	0.012	0.79	848	
		2	2	0.4	0.300	2.40	1,789	
		2	3	0.4	0.334	2.90	2,030	
		1	4	0.4	0.026	1.98	1,577	
		1	5	0.4	0.032	2.55	1,866	
		2	6	0.4	0.282	2.14	1,661	
		3	7	0.3	0.009	0.002	17	
		3	8	0.3	0.125	0.058	150	
		2	Torpedo.	0.75	0.036	1.60	1,363	
141	Explosive, O. P. Co. compound; ring, 4 foot; charge, 18 pounds; submergence, 35 feet; depth of water, 102 feet; case, wooden, 12-inch cube of 1-inch pine, air space; ignition, Smith's battery, 2 Dowse-Smith glycerine fuses. Effects: Normal.	1	1	0.4	0.103	30.85	9,816	
		2	2	0.75	0.153	40.60	11,805	
		2	3	0.75	0.131	32.33	10,144	
		1	4	0.4	0.128	41.70	12,018	
		1	5	0.4	0.086	24.07	8,330	
		2	6	0.75	0.063	12.50	5,381	
		3	7	0.3	0.088	0.95	964	
		3	8	0.3	0.071	0.71	795	
142	Explosive, O. P. Co. compound; ring, 4 foot; charge, 18 pounds; submergence, 35 feet; depth of water, 102 feet; case, wooden, 12-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Schooner passing at 100 yards was so shaken that man ran from wheel badly frightened.	1	1	0.4	0.098	28.71	9,368	
		2	2	0.75	0.103	23.44	8,183	
		2	3	0.75	0.144	37.06	11,107	
		1	4	0.4	0.104	31.29	9,904	
		1	5	0.4	0.080	21.96	7,836	
		2	6	0.75	0.058	11.28	5,023	
		3	7	0.3	0.050	0.44	578	
		3	8	0.3	0.063	0.60	714	
143	Explosive, dynamite No. 1; ring, 5 foot; charge, 1 pound; submergence, 35 feet; depth of water, 85 feet; case, glass bottle, packed; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	3	1	0.75	0.251	.....	......	Defective.
		1	2	0.4	0.066	17.07	6,624	
		1	3	0.4	0.048	11.39	5,039	
		3	4	0.75	0.104	9.21	4,390	
		3	5	0.75	0.081	6.65	3,532	
		1	6	0.4	0.054	13.21	5,576	
		3	7	0.3	0.024	0.17	304	
		3	8	0.3	0.042	0.36	502	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
144	Explosive, dualin; ring, 5 foot; charge, 1 pound; submergence, 35 feet; depth of water, 85 feet; case, glass bottle, sand tamped; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Normal.	3	1	0.75	0.142	13.96	5,792	
		1	2	0.4	0.075	20.08	7,382	
		1	3	0.4	0.072	19.08	7,135	
		3	4	0.75	0.101	8.84	4,273	
		3	5	0.75	0.111	10.05	4,656	
		1	6	0.4	0.052	12.62	5,395	
		3	7	0.3	0.037	0.30	451	
		3	8	0.3	0.056	0.52	643	
145	Explosive, dualin; ring, 5 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 85 feet; case, glass bottle, full; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Normal.	3	1	0.75	.....	......	......	Spring broken.
		1	2	0.4	0.114	35.38	10,768	
		1	3	0.4	0.108	32.82	10,244	
		3	4	0.75	0.197	22.08	7,864	
		3	5	0.75	0.189	20.83	7,466	
		1	6	0.4	0.092	26.32	8,841	
		3	7	0.3	0.154	2.07	1,622	
		3	8	0.3	0.045	0.38	524	
146	Explosive, dynamite No. 1; ring, 5 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 85 feet; case, glass bottle, sand tamped; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Suspension strap broke and let ring fall.	3	1	0.75	0.281	......	......	Bad gauge pin.
		1	2	0.4	0.128	41.70	12,018	
		1	3	0.4	0.098	28.71	9,368	
		3	4	0.75	0.198	22.25	7,907	
		3	5	0.75	0.158	16.24	6,408	
		1	6	0.4	0.087	24.44	8,416	
		3	7	0.3	0.038	0.31	463	
		3	8	0.3	0.081	0.84	887	
147	Explosive, dynamite No. 1; ring, 5 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 100 feet; case, glass bottle, full; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	3	1	0.75	0.483	......	......	Defective.
		1	2	0.4	0.213	......	......	Do.
		1	3	0.4	0.142	48.56	13,303	
		3	4	0.75	0.270	34.62	10,617	
		3	5	0.75	0.225	26.67	8,920	
		1	6	0.4	0.097	28.28	9,276	
		3	7	0.3	0.040	0.34	487	
		3	8	0.3	0.118	1.39	1,248	
148	Explosive, gun-cotton; ring, 5 foot; charge, 1 pound; submergence, 35 feet; depth of water, 100 feet; case, wooden, of 1-inch pine, sand tamped; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	3	1	0.75	0.060	4.58	2,736	
		1	2	0.4	0.036	7.96	3,988	
		1	3	0.4	0.040	9.10	4,356	
		3	4	0.75	0.065	5.04	2,937	
		3	5	0.75	0.066	5.13	2,973	
		1	6	0.4	0.024	4.84	2,855	
		3	7	0.3	0.012	0.07	172	
		3	8	0.3	0.037	0.30	451	
149	Explosive, gun-cotton; ring, 5 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 100 feet; case, wooden, of 1-inch pine, sand tamped; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	3	1	0.75	0.140	13.71	5,724	
		1	2	0.4	0.054	13.21	5,576	
		1	3	0.4	0.064	16.42	6,453	
		3	4	0.75	0.141	13.83	5,758	
		3	5	0.75	0.113	10.28	4,725	
		1	6	0.4	0.045	10.45	4,776	
		3	7	0.3	0.042	0.36	502	
		3	8	0.3	0.063	0.60	714	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
150	Explosive, gun-cotton; ring, 5 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 100 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	3	1	0.75	0.372	58.05	14,942	
		1	2	0.4	0.086	24.07	8,330	
		1	3	0.4	0.078	21.21	7,654	
		3	4	0.75	0.144	14.20	5,861	
		3	5	0.75	0.160	16.54	6,488	
		1	6	0.4	0.051	12.32	5,305	
		3	7	0.3	0.042	0.36	502	
		3	8	0.3	0.070	0.70	788	
151	Explosive, dualin; ring, 5 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 80 feet; case, tin can, sand tamped; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Normal.	3	1	0.75	.....	......	......	Hammered.
		1	2	0.4	0.161	58.41	15,044	
		1	3	0.4	0.127	41.28	11,935	
		3	4	0.75	0.278	36.28	10,954	
		3	5	0.75	0.314	43.92	12,441	
		1	6	0.4	0.127	41.28	11,935	
		3	7	0.3	0.086	0.92	943	
		3	8	0.3	0.123	1.48	1,297	
152	Explosive, dynamite No. 1; ring, 5 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 79 feet; case, tin can, sand tamped; ignition, Smith's battery, 1 Mowbray fuze. Effects: Normal.	2	1	0.75	0.173	48.20	13,236	
		1	2	0.4	0.142	48.56	13,303	
		1	3	0.4	0.135	45.20	12,677	
		2	4	0.75	0.132	32.68	10,216	
		2	5	0.75	0.132	32.68	10,216	
		1	6	0.4	0.134	44.67	12,578	
		3	7	0.3	0.108	1.24	1,152	
		3	8	0.3	0.118	1.39	1,248	
153	Explosive, dualin; ring, 5 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 80 feet; case, tin can, sand tamped; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Shank of gauge-socket broken, and ring partly split on inner edge.	2	1	0.5	0.428	53.03	14,184	
		1	2	0.4	0.173	64.72	16,109	
		1	3	0.4	0.162	58.91	15,130	
		2	4	0.5	0.367	41.38	11,956	
		2	5	0.5	0.356	39.35	11,558	
		1	6	0.4	0.073	19.42	7,218	
		3	7	0.3	0.117	1.38	1,237	
		3	8	0.3	0.115	1.34	1,217	
154	Explosive, gun-cotton; ring, 5 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 80 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	2	1	0.5	0.217	18.81	7,067	
		1	2	0.4	0.110	33.62	10,412	
		1	3	0.4	0.087	24.44	8,416	
		2	4	0.5	0.195	16.13	6,366	
		2	5	0.5	0.210	17.95	6,852	
		1	6	0.4	0.069	18.08	6,884	
		3	7	0.3	0.096	1.05	1,035	
		3	8	0.3	0.087	0.93	954	
155	Explosive, dualin; ring, 5 foot; charge, 6½ pounds; submergence, 35 feet; depth of water, 65 feet; case, wooden, 6-inch cube of 2-inch pine, full; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: The ponton raft was distant about 50 feet from buoy; water in bottom was thrown up in little jets by the shock.	2	1	0.75	0.194	56.71	14,750	
		1	2	0.4	0.172	64.18	16,018	
		1	3	0.4	0.188	73.19	17,487	
		2	4	0.75	0.144	37.06	11,107	
		2	5	0.75	0.149	39.04	11,501	
		1	6	0.4	0.144	49.60	13,492	
		3	7	0.3	0.108	1.24	1,152	
		3	8	0.3	0.269	5.00	2,922	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
156	Explosive, dynamite No. 1; ring, 5 foot; charge, 10 pounds; submergence, 35 feet; depth of water, 65 feet; case, wooden, 6-inch cube of 2-inch pine, full; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Small connecting shackle-bolt parted, letting ring down; gauge-pins No. 2 and No. 6 slightly upset.	2	1	0.75	0.268	90.02	20,072	
		1	2	0.4	0.176	66.37	16,383	
		1	3	0.4	0.219	93.47	20,582	
		2	4	0.75	0.248	80.50	18,630	
		2	5	0.75	0.206	61.89	15,634	
		1	6	0.4	0.132	43.62	12,381	
		3	7	0.3	0.212	3.34	2,232	
		3	8	0.3	0.186	2.76	1,967	
157	Explosive, dualin; ring, 3 foot; charge, 1 pound; submergence, 35 feet; depth of water, 92 feet; case, glass bottle, sand tamped; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Normal.	3	1	0.75	0.506	101.30	21,715	
		1	2	0.4	0.231	102.10	21,835	
		1	3	0.4	0.195	77.22	18,120	
		3	4	0.75	0.366	56.43	14,729	
		3	5	0.75	0.333	48.09	13,217	
		1	6	0.4	0.142	48.56	13,303	
		3	7	0.3	0.073	0.73	810	
		3	8	0.3	0.070	0.70	788	
158	Explosive, dualin; ring, 3 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 92 feet; case, glass bottle, full; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Ring of suspension strap broke, letting ring down; steel pin of gauge No. 2 was upset.	3	1	0.75	0.616	153.30	28,620	
		1	2	0.4	.....	......	......	Disabled.
		1	3	0.4	0.260	124.60	24,930	
		3	4	0.75	0.518	106.20	22.410	
		3	5	0.75	0.494	97.19	21,128	
		1	6	0.4	0.227	99.21	21,418	
		3	7	0.3	0.134	1.67	1,408	
		3	8	0.3	0.078	0.79	856	
159	Explosive, mortar powder; ring, 3 foot; charge, 50 pounds; submergence, 35 feet; depth of water, 105 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 1 Abel powder fuze. Effects: Normal; cable-gauge hit ring-gauge No. 2 doing no damage.	1	1	0.4	0.042	3.56	2,329	
		3	2	0.75	0.249	3.92	2,247	
		3	3	0.75	0.233	3.56	2,331	
		1	4	0.4	0.053	4.78	2,835	
		1	5	0.4	0.034	2.74	1,961	
		3	6	0.75	0.160	2.10	1,640	
		3	7	0.3	0.075	0.029	94	
		3	8	0.3	0.047	0.016	62	
		2	Torpedo.	0.75	0.051	2.49	1,834	
160	Explosive, mortar powder; ring, 3 foot; charge, 50 pounds; submergence, 35 feet; depth of water, 105 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 1 Abel powder fuze. Effects: Normal.	1	1	0.4	0.042	3.56	2,329	
		3	2	0.75	0.228	3.46	2,286	
		3	3	0.75	0.278	4.65	2,781	
		1	4	0.4	0.111	12.59	5,407	
		1	5	0.4	0.071	6.93	3,632	
		3	6	0.75	0.306	5.34	3,058	
		3	7	0.3	0.028	0.008	41	
		3	8	0.3	0.033	0.01	46	
		2	Torpedo.	0.75	0.020	0.77	838	
161	Explosive, mortar powder; ring 3 foot; charge, 50 pounds; submergence, 35 feet; depth of water, 105 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Torpedo gauge fouled in ring, bending the wire rope sharply.	1	1	0.4	0.042	3.56	2,329	
		3	2	0.75	0.273	4.47	2,723	
		3	3	0.75	0.306	5.37	3,066	
		1	4	0.4	0.039	3.26	2,195	
		1	5	0.4	0.040	3.36	2,242	
		3	6	0.75	0.120	1.42	1,262	
		3	7	0.3	0.028	0.008	39	
		3	8	0.3	0.069	0.026	89	
		2	Torpedo.	0.75	0.057	2.86	2,012	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
162	Explosive, mortar powder; ring, 3 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 105 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 1 Abel powder fuze. Effects: Normal.	1	1	0.4	0.133	16.32	6,428	
		3	2	0.75	0.524	13.79	5,747	
		3	3	0.75	0.663	20.90	7,582	
		1	4	0.4	0.196	28.78	9,384	
		1	5	0.4	0.134	16.51	6,479	
		3	6	0.75	0.502	12.67	5,432	
		3	7	0.3	0.038	0.012	52	
		3	8	0.3	0.143	0.070	170	
		1	Torpedo.	0.6	0.012	0.026	86	Defective.
163	Explosive, gun-cotton; ring, 3 foot; charge, 1 pound; submergence, 35 feet; depth of water, 105 feet; case, wooden, of 1-inch pine, sand tamped; ignition, Smith's battery; 1 Abel fuze. Effects: Normal.	1	1	0.4	0.133	44.14	12,479	
		3	2	0.75	0.222	26.22	8,819	
		3	3	0.75	0.221	26.07	8,786	
		1	4	0.4	0.098	28.71	9,368	
		1	5	0.4	0.103	30.85	9,816	
		3	6	0.75	0.214	24.90	8,517	
		3	7	0.3	0.016	0.10	209	
		3	8	0.3	0.025	0.18	319	
164	Explosive, gun-cotton; ring, 3 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 110 feet; case, wooden, of 1-inch pine, sand tamped; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	1	1	0.4	0.180	68.67	16,757	
		3	2	0.75	0.386	61.92	15,642	
		3	3	0.75	0.378	59.70	15,493	
		1	4	0.4	0.180	68.67	16,757	
		1	5	0.4	0.095	27.44	9,092	
		3	6	0.75	0.388	62.53	15,740	
		3	7	0.3	0.056	0.52	643	
		3	8	0.3	0.064	0.61	721	
165	Explosive, gun-cotton; ring, 3 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 110 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	1	1	0.4	0.164	59.92	15,303	
		2	2	0.75	0.201	59.84	15,289	
		2	3	0.75	0.179	50.48	13,655	
		1	4	0.4	0.175	65.80	16,290	
		1	5	0.4	0.150	52.64	14,040	
		2	6	0.75	0.156	41.77	12,030	
		3	7	0.3	0.048	0.42	556	
		3	8	0.3	0.063	0.60	714	
166	Explosive, gun-cotton; ring, 3 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 110 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	1	1	0.4	0.182	69.81	16,942	
		2	2	0.75	0.251	81.93	18,852	
		2	3	0.75	0.243	78.09	18,255	
		1	4	0.4	0.242	110.40	22,896	
		1	5	0.4	0.180	68.67	16,757	
		2	6	0.75	0.254	83.34	19,068	
		3	7	0.3	0.074	0.74	818	
		3	8	0.3	0.060	0.58	695	
167	Explosive, dualin; ring, 3 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 110 feet; case, tin can, sand tamped; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Normal.	1	1	0.4	0.114	......	......	Pin badly jammed.
		2	2	0.75	0.293	103.00	21,959	
		2	3	0.75	0.299	106.30	22,418	
		1	4	0.4	0.267	130.40	25,701	
		1	5	0.4	0.130	42.56	12,183	
		2	6	0.75	0.381	157.70	29,178	
		3	7	0.3	0.138	1.74	1,444	
		3	8	0.3	0.114	1.33	1,208	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
168	Explosive, dualin; ring, 3 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 110 feet; case, tin can, sand tamped; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Ring fractured in two places through lashing-ring holes; the section was 4.5 × 1.5 inches, and the hole 1.5 × $\frac{11}{16}$ inches; metal, good wrought iron, first used to-day; other damage to iron work.	1	1	0.4	0.250	116.50	23,840	
		2	2	0.75	0.345	133.00	26,045	
		2	3	0.75	0.330	124.30	24,885	
		1	4	0.4	0.222	95.62	20,898	
		1	5	0.4	0.123	......	......	Badly jammed pin.
		2	6	0.75	0.324	120.70	24,405	
		3	7	0.3	0.161	2.22	1,699	
		3	8	0.3	0.163	2.25	1,718	
169	Explosive, Orange Lightning powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 100 feet; case, wooden, of 2-inch piue; ignition, Smith's battery, 1 Abel powder fuze. Effects: Charge, half of No. 2 and half of No. 5 grade; both excellent sporting powder; broke shank of gauge socket by bending ring; circular rainbow seen in spray.	2	1	0.75	0.383	41.37	11,953	
		1	2	0.4	0.335	71.72	17,253	
		1	3	0.4	0.314	63.93	15,975	
		2	4	0.75	0.387	42.14	12,100	
		2	5	0.75	0.345	34.47	11,430	
		1	6	0.4	0.262	46.67	12,955	
		3	7	0.3	0.114	0.05	137	
		3	8	0.3	0.245	0.16	299	
		2	Torpedo.	0.75	0.388	42.31	12,135	
170	Explosive, Orange Lightning powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 100 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Charge, half of No. 3 and half of No. 5 grade, both excellent sporting powder; ring parted at one lashing-ring hole and cracked at another. (See No. 168 for size.)	2	1	0.75	0.466	59.41	14,090	
		1	2	0.4	0.355	79.78	18,517	
		1	3	0.4	0.269	48.80	13,345	
		2	4	0.75	0.369	38.69	11,457	
		2	5	0.75	0.380	40.77	11,837	
		1	6	0.4	0.265	47.61	13,127	
		3	7	0.3	0.096	0.04	118	
		3	8	0.3	0.268	0.19	331	
		2	Torpedo.	0.75	0.435	52.16	13,953	
171	Explosive, mortar powder; ring, 3 foot; charge, 25 pounds; submergence, 35 feet; depth of water, 100 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 2 Dowse-Smith glycerine-fuzes. Effects: Jet 10 to 15 feet high, which rose only after buoy had shot up its length and fallen back.	3	1	0.4	0.552	1.45	1,280	
		3	2	0.4	0.578	1.62	1,378	
		3	3	0.4	0.588	1.70	1,424	
		3	4	0.4	0.524	1.29	1,184	
		3	5	0.4	0.526	1.30	1,190	
		3	6	0.4	0.560	1.50	1,310	
		3	7	0.3	0.012	0.003	20	
		3	8	0.3	0.018	0.003	26	
		2	Torpedo.	0.4	0.091	0.40	536	
172	Explosive, mortar powder; ring, 3 foot; charge, 25 pounds; submergence, 35 feet; depth of water, 100 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Like last.	3	1	0.75	0.061	0.58	701	
		3	2	0.6	0.224	3.37	2,247	
		3	3	0.6	0.307	2.15	1,666	
		3	4	0.75	0.087	0.92	943	
		3	5	0.75	0.076	0.81	870	
		3	6	0.6	0.304	2.12	1,649	
		3	7	0.3	0.005	0.001	11	
		3	8	0.3	0.118	0.054	142	
		2	Torpedo.	0.4	0.179	1.03	1,016	
173	Explosive, mortar powder; ring 3 foot; charge, 25 pounds; submergence, 35 feet; depth of water, 100 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Like last.	3	1	0.75	0.066	0.65	752	
		3	2	0.6	0.254	1.60	1,367	
		3	3	0.6	0.287	1.93	1,552	
		3	4	0.75	0.098	1.08	1,048	
		3	5	0.75	0.081	0.83	888	
		3	6	0.6	0.335	2.45	1,818	
		3	7	0.3	0.006	0.001	12	
		3	8	0.3	0.012	0.003	20	
		3	Torpedo.	0.4	0.477	1.07	1,045	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
174	Explosive, mortar powder; ring, 3 foot; charge, 25 pounds; submergence, 35 feet; depth of water, 100 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Like last shot.	3	1	0.75	0.097	1.06	1,037	
		3	2	0.6	0.246	1.52	1,320	
		3	3	0.6	0.203	1.13	1,087	
		3	4	0.75	0.121	1.44	1,271	
		3	5	0.75	0.105	1.19	1,120	
		3	6	0.6	0.343	2.54	1,862	
		3	7	0.3	0.004	0.001	10	
		3	8	0.3	0.015	0.004	23	
		3	Torpedo.	0.4	0.478	1.07	1,048	
175	Explosive, mortar powder; ring, 3 foot; charge, 25 pounds; submergence, 35 feet; depth of water, 98 feet; case, Confederate frame torpedo of 1.5 inch cast iron, weighing 386 pounds, just filled; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Extra oil cask float; jet similar to last shot; ring struck by 6 fragments but not hurt; small groove cut round torpedo to divert fragments by forming fracture in ring plane.	3	1	0.75	0.659	23.84	8,278	
		3	2	0.6	0.738	11.44	5,074	
		3	3	0.6	0.710	10.27	4,721	
		3	4	0.75	0.510	13.08	5,549	
		3	5	0.75	0.421	9.19	4,385	
		3	6	0.6	0.588	6.53	3,491	
		3	7	0.3	0.019	0.005	27	
		3	8	0.3	0.096	0.04	118	
176	Explosive, mortar powder; ring, 3 foot; charge, 25 pounds; submergence, 35 feet; depth of water, 98 feet; case, wooden, of 2-inch pine; ignition, Smith's battery, 2 Dowse-Smith glycerine fuzes. Effects: Normal.	3	1	0.6	0.238	1.44	1,276	
		3	2	0.6	0.234	1.40	1,254	
		3	3	0.75	0.080	0.82	879	
		3	4	0.4	0,524	2.87	2,018	
		3	5	0.6	0.189	1.01	1,009	
		3	6	0.75	0.096	1.05	1,026	
		3	Torpedo.	0.6	0.187	1.00	996	
177	Explosive, dualin; ring, 5 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 108 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.5	0.125	52.06	13,933	Shows rounded edges.
		1	2	0.4	0.119	37.60	11,215	
		1	3	0.4	0.128	41.70	12,018	
		1	4	0.5	0.116	46.66	12,952	Shows rounded edges.
		1	5	0.5	0.129	54.42	14,349	
		1	6	0.4	0.140	47.52	13,113	
		3	7	0.3	0.051	0.45	588	
		3	8	0.3	0.088	0.95	964	
178	Explosive, gun-cotton; ring, 5 foot; charge, 4 pounds; submergence, 68 feet; depth of water, 108 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Buoy did not move; in about 15 or 20 seconds gas rose like a balloon through water and made a bubbling; diameter of the appearance when first seen below surface, about 20 feet.	1	1	0.5	0.055	17.18	6,655	
		1	2	0.4	0.095	27.44	9,092	
		1	3	0.4	0.076	20.46	7,473	
		1	4	0.5	0.043	12.84	5,477	
		1	5	0.5	0.091	33.22	10,328	
		1	6	0.4	0.077	20.83	7,564	
		3	7	0.3	0.016	0.10	209	
		..	8	...	.....	......	......	None used.
		3	9	0.3	0.016	0.10	209	
		3	10	0.3	0.056	0.52	656	
179	Explosive, dualin; ring, 5 foot; charge, 5 pounds; submergence, 68 feet; depth of water, 108 feet; case, wooden, 6-inch cube of 2-inch pine, sand tamping; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Similar to last; balloon rose in 12 seconds.	1	1	0.5	0.132	56.24	14,668	
		1	2	0.4	0.135	45.20	12,677	
		1	3	0.5	0.091	33.22	10,328	
		1	4	0.5	0.083	29.35	9,509	
		1	5	0.5	0.136	58.76	15,105	
		1	6	0.4	0.130	42.56	12,183	
		3	7	0.3	0.019	0.11	234	
		..	8	...	.....	......	......	None used.
		3	9	0.3	0.035	0.27	427	
		3	10	0.3	0.075	0.75	825	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
180	Explosive, mortar powder; ring, 5 foot; charge, 300 pounds; submergence, 55 feet; depth of water, 108 feet; case, wooden. of 3-inch hemlock (22 inches); ignition, Smith's battery, 9 Dowse-Smith glycerine fuzes. Effects: Huge jet and large wave; fragment of case fell by boat 300 feet distant from the buoy; wire rope (1-inch) torn in two pieces, and guard rope parted; lowering rope saved ring; gauge lost by broken shackle.	1	1	0.5	0.162	46.82	12,979	
		1	2	0.75	0.091	125.70	25,072	
		1	3	0.75	0.032	32.30	10,118	
		1	4	0.5	0.201	64.79	16,118	
		1	5	0.5	0.083	18.00	6,863	
		1	6	0.75	0.025	23.40	8,175	
		3	7	0.3	0.074	0.75	824	
		...	8	...	.....	......	......	None used.
		...	9	...	.....	......	......	Do.
		3	10	0.3	0.420	0.48	612	
	Last shot fired in 1871 (November 9).	2	Torpedo.	0.75	.....	......	......	Lost gauge.
181	Explosive, dualin, wet, and dynamite, No. 1, dry; ring, 4 foot; charge, 4 + 1 pounds; submergence, 35 feet; depth of water, 108 feet; case, can No. 2; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Dynamite in 1-pound tin can, bedded in dualin wet with fresh water, and open to leakage; water boiled up a little.	1	1	0.4	0.138	46.59	12,989	
		1	2	0.4	0.148	51.03	13,859	
		1	3	0.4	0.140	47.52	13,113	
		1	4	0.4	0.130	42.56	12,183	
		1	5	0.4	0.136	45.66	12,764	
		1	6	0.4	0.126	40.85	11,853	
		3	7	0.3	0.085	0.90	932	
	First shot of season (May 30, 1872).	3	8	0.3	0.080	0.82	876	
182	Explosive, dualin and dynamite No. 1; ring, 4 foot; charge, 4 + 1 pounds; submergence, 35 feet; depth of water, 108 feet; case, can No. 2; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Arrangement like last, except that dualin was dry; effect vastly greater; a marked dome formed.	1	1	0.4	0.222	95.62	20,898	
		1	2	0.4	0.247	114.20	23,531	
		1	3	0.4	0.270	132.80	26,010	
		1	4	0.4	0.262	126.30	25,156	
		1	5	0.4	0.242	110.40	22,898	
		1	6	0.4	0.227	99.21	21,418	
		3	7	0.3	0.202	3.10	2,124	
		3	8	0.3	0.152	2.02	1,599	
183	Explosive, dynamite No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 98 feet; case, fuze can; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.113	34.94	10,679	
		1	2	0.4	0.110	33.62	10,412	
		1	3	0.4	0.085	23.69	8,244	
		1	4	0.4	0.080	21.96	7,836	
		1	5	0.4	0.097	28.28	9,276	
		1	6	0.4	0.070	18.42	6,971	
		3	7	0.3	0.029	0.21	355	
		3	8	0.3	0.054	0.49	620	
184	Explosive, dynamite No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 98 feet; case, fuze can; ignitiou, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.095	27.44	9,092	
		1	2	0.4	0.126	40.85	11,853	
		1	3	0.4	0.085	23.69	8,244	
		1	4	0.4	0.093	26.69	8,925	
		1	5	0.4	0.091	25.94	8,758	
		1	6	0.4	0.093	26.69	8,925	
		3	7	0.4	0.033	0.40	545	
		3	8	0.4	0.026	0.30	450	
185	Explosive, dynamite No. 1, wet and dry; ring, 4 foot; charge, 4 + 1 pounds; submergence, 35 feet; depth of water, 98 feet; case, can No. 2; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Dynamite dry in fuze can, bedded in 4 pounds wet with fresh water and open to leakage, in can No. 2; usual effect for 5-pound dry charge.	1	1	0.4	0.209	86.37	19,525	
		1	2	0.4	0.262	126.30	25,156	
		1	3	0.4	0.235	105.10	22,255	
		1	4	0.4	0.177	66.95	16,477	
		1	5	0.4	0.242	110.40	22,898	
		1	6	0.4	0.199	79.81	18,524	
		3	7	0.4	0.118	2.21	1,698	
		3	8	0.4	0.088	1.48	1,300	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
186	Explosive, dynamite No. 1; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 98 feet; case, can No. 2; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Arrangement as in last shot, except entire charge was dry; broke ring of suspension strap.	1	1	0.4	0.251	117.30	23,948	
		1	2	0.4	0.266	129.60	25,596	
		1	3	0.4	0.213	89.13	19,938	
		1	4	0.4	0.220	94.20	20,690	
		1	5	0.4	0.266	129.60	25,596	
		1	6	0.4	0.204	83.16	19,041	
		3	7	0.4	0.115	2.13	1,655	
		3	8	0.4	0.091	1.55	1,336	
187	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 98 feet; case, 24-gallon keg diaphragmed, air space up; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.210	32.16	10,107	
		1	2	0.4	0.183	28.01	8,772	
		1	3	0.4	0.225	36.13	10,922	
		1	4	0.4	0.097	10.46	4,778	
		1	5	0.4	0.155	20.41	7,463	
		1	6	0.4	0.103	11.35	5,047	
		3	7	0.4	0.092	0.038	114	
		3	8	0.4	0.083	0.034	105	
188	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 98 feet; case, 24-gallon keg diaphragmed, air space down; ignition, Smith's battery, 1 Dowse-Smith glycerine fuse. Effects: Normal.	1	1	0.4	0.074	7.30	3,760	
		1	2	0.4	0.072	7.05	3,675	
		1	3	0.4	0.067	6.44	3,460	
		1	4	0.4	0.086	8.90	4,288	
		1	5	0.4	0.068	6.57	3,503	
		1	6	0.4	0.130	15.73	6,273	
		3	7	0.4	0.037	0.023	81	
		3	8	0.4	0.076	0.058	150	
189	Explosive, musket powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 98 feet; case, 24-gallon keg diaphragmed, air space up; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.105	11.64	5,133	
		1	2	0.4	0.210	32.16	10,107	
		1	3	0.4	0.114	13.07	5,544	
		1	4	0.4	0.148	19.09	7,138	
		1	5	0.4	0.114	13.07	5,544	
		1	6	0.4	0.165	22.35	7,929	
		3	7	0.4	0.074	0.056	146	
		3	8	0.4	0.128	0.117	239	
190	Explosive, musket powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 98 feet; case, 24-gallon keg diaphragmed, air space down; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.084	8.63	4,204	
		1	2	0.4	0.087	9.04	4,332	
		1	3	0.4	0.160	21.41	7,706	
		1	4	0.4	0.113	12.81	5,498	
		1	5	0.4	0.303	59.80	15,280	
		1	6	0.4	0.224	35.87	10,869	
		3	7	0.4	0.079	0.061	154	
		3	8	0.4	0.088	0.070	170	
191	Explosive, dualin, wet, and dynamite No. 1, dry; ring, 4 foot; charge, 4 + ½ pounds; submergence, 35 feet; depth of water, 100 feet; case, can No. 2 and fuze can inside of it; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.151	53.14	14,128	
		1	2	0.4	0.174	65.26	16,199	
		1	3	0.4	0.137	46.13	12,851	
		1	4	0.4	0.169	......	......	Lead bent.
		1	5	0.4	0.137	46.13	12,851	
		1	6	0.4	0.151	53.14	14,128	
		3	7	0.4	0.066	1.03	1,018	
		3	8	0.4	0.051	0.73	806	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
192	Explosive, dualin, wet, and dynamite No. 1, dry; ring, 4 foot; charge, 4 + ¾ pounds; submergence, 35 feet; depth of water, 100 feet; case, can No. 2, and fuze can inside; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Fired on June 14, 1872; almost a tornado followed; had to anchor ring to lighten raft; small boat broke loose and drifted ashore with battery; baling water for an hour to keep from swamping.	1	1	0.4	0.188	46.50	12,939	
		1	2	0.4	0.164	59.92	15,308	
		1	3	0.4	0.129	42.13	12,100	
		1	4	0.4	0.112	34.50	10,590	
		1	5	0.4	0.122	39.00	11,491	
		1	6	0.4	0.128	41.70	12,018	
		3	7	0.4	0.050	0.71	795	
		3	8	0.4	.....	.....	......	Lost in storm.
193	Explosive, dynamite No. 1, wet and dry; ring, 4 foot; charge, 4 + ¾ pounds; submergence, 35 feet; depth of water, 100 feet; case, can No. 2, and fuze can inside; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Charge soaked for 4 days. Effects: Red vapor and fumes rose after explosion.	1	1	0.4	0.183	70.38	17,085	
		1	2	0.4	0.223	96.33	21,002	
		1	3	0.4	0.236	105.80	22,360	
		1	4	0.4	0.172	64.18	16,018	Pin broken at base.
		1	5	0.4	0.257	122.10	24,600	
		1	6	0.4	0.188	73.19	17,487	
		3	7	0.4	0.061	0.91	941	
		3	8	0.4	0.083	1.38	1,239	
194	Explosive, dynamite No. 1, wet and dry; ring, 4 foot; charge, 4 + ¾ pounds; submergence, 35 feet; depth of water, 100 feet; case, can No. 2, and fuze can inside; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Like last shot.	1	1	0.4	0.210	87.00	19,620	
		1	2	0.4	0.221	94.91	20,794	
		1	3	0.4	0.198	79.16	18,423	
		1	4	0.4	0.245	112.70	23,325	
		1	5	0.4	0.203	82.48	18,937	
		1	6	0.4	0.191	74.88	17,756	
		3	7	0.4	0.095	1.65	1,395	
		3	8	0.4	0.058	0.85	899	
195	Fired in the Crate.—See Appendix B.							
196	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 110 feet; case, can No. 1, sawdust tamped, up; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.182	69.81	16,942	
		1	2	0.4	0.214	89.84	20,044	
		1	3	0.4	0.182	69.81	16,942	
		1	4	0.4	0.184	70.95	17,127	
		1	5	0.4	0.152	53.64	14,216	
		1	6	0.4	0.180	68.67	16,757	
		3	7	0.4	0.083	1.38	1,239	
		3	8	0.4	0.042	0.57	683	
197	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 110 feet; case can No. 1, sawdust tamped, down; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.152	53.64	14,216	
		1	2	0.4	0.212	88.42	19,832	
		1	3	0.4	0.161	58.41	15,044	
		1	4	0.4	0.205	83.84	19,145	
		1	5	0.4	0.151	53.14	14,128	
		1	6	0.4	0.148	51.03	13,859	
		3	7	0.4	0.081	1.33	1,210	
		3	8	0.4	0.066	1.03	1,018	
198	Explosive, dynamite No. 1, compacted; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 110 feet; case, can No. 1, sand tamped, up; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.198	79.16	18,423	
		1	2	0.4	0.214	89.84	20,044	
		1	3	0.4	0.173	64 72	16,109	
		1	4	0.4	0.161	58.41	15,044	
		1	5	0.4	0.159	57.35	14,862	
		1	6	0.4	0.173	64.72	16,109	
		3	7	0.4	0.069	1.08	1,053	
		3	8	0.4	0.053	0.76	834	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
199	Explosive, dynamite No. 1, compacted; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 110 feet; case, can No. 1, sand tamped, down; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.179	68.10	16,664	
		1	2	0.4	0.214	89.84	20,044	
		1	3	0.4	0.168	59.42	15,217	
		1	4	0.4	0.186	71.52	17,220	
		1	5	0.4	0.150	52.64	14,040	
		1	6	0.4	0.165	60.43	15,390	
		3	7	0.4	0.068	1.06	1,041	
		3	8	0.4	0.057	0.84	887	
200	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 110 feet; case, can No. 2, sawdust tamped, up; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.288	107.30	22,570	
		1	2	0.4	0.208	82.48	18,937	
		1	3	0.4	0.153	54.15	14,304	
		1	4	0.4	0.145	50.12	13,587	
		1	5	0.4	0.128	41.70	12,018	
		1	6	0.4	0.142	48.56	13,303	
		3	7	0.4	0.075	1.20	1,129	
		3	8	0.4	0.060	0.89	925	
201	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 110 feet; case, can No. 2, sawdust tamped, down; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0·4	0.135	45.20	12,677	
		1	2	0.4	0.191	74.88	17,756	
		1	3	0.4	0.135	45.20	12,677	
		1	4	0.4	0.132	43.62	12,381	
		1	5	0.4	0.165	60.43	15,390	
		1	6	0.4	0.133	44.14	12,479	
		3	7	0.4	0.123	2.34	1,762	
		3	8	0.4	0.043	0.58	698	
202	Explosive, dynamite No. 1, compacted; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 110 feet; case, can No. 2, sand tamped, up; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.245	112.70	23,325	
		1	2	0.4	0.229	100.67	21,626	
		1	3	0.4	0.160	57.90	14,957	
		1	4	0.4	0.151	53.14	14,128	
		1	5	0.4	0.166	60.96	15,479	
		1	6	0.4	0.176	66.37	16,383	
		3	7	0.4	0.075	1.20	1,129	
		3	8	0.4	0.069	1.06	1,053	
203	Explosive, dynamite No. 1, compacted; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 110 feet; case, can No. 2, sand tamped, up; ignition, Smith's battery, 1 Dowse-Smith glycerine fuze. Effects: Normal.	1	1	0.4	0.218	92.74	20,474	
		1	2	0.4	0.277	138.70	26,778	
		1	3	0.4	0.142	48.56	13,303	
		1	4	0.4	0.180	68.67	16,757	
		1	5	0.4	0.110	33.62	10,412	
		1	6	0.4	0.150	52.64	14,040	
		3	7	0.4	0.085	1.43	1,268	
		3	8	0.4	0.055	0.80	861	
204	Explosive, nitro-glycerine (Chester's); ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 100 feet; case, can No. 1, open; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Normal.	1	1	0.4	0.143	49.08	13,397	
		1	2	0.4	0.171	......	......	Defective lead.
		1	3	0.4	0.099	29.13	9,460	
		I	4	0.4	0.102	30.42	9,728	
		1	5	0.4	0.090	25.57	8,674	
		1	6	0.4	0.102	30.42	9,728	
		3	7	0.4	0.073	1.16	1,103	
		3	8	0.4	0.045	0.62	727	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
205	Explosive, nitro-glycerine (Chester's); ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 92 feet; case, can No. 2, open; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Normal.	1	1	0.4	0.135	45.20	12,677	
		1	2	0.4	0.127	41.28	11,935	
		1	3	0.4	0.126	40.85	11,853	
		1	4	0.4	0.152	53.64	14,216	
		1	5	0.4	0.162	58.91	15,130	
		1	6	0.4	0.166	60.96	15,479	
		3	7	0.4	0.097	1.69	1,422	
		3	8	0.4	0.103	1.84	1,498	
206	Explosive, nitro-glycerine (Chester's); ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 100 feet; case, fuze can, open; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Normal; bubbling began in 7 seconds after explosion.	1	1	0.4	0.100	29.55	9,552	
		1	2	0.4	0.156	.....	.....	Defective lead.
		1	3	0.4	0.076	20.46	7,473	
		1	4	0.4	0.071	18.75	7,053	
		1	5	0.4	0.058	14.49	5,938	
		1	6	0.4	0.061	15.47	6,203	
		3	7	0.4	0.053	0.76	834	
		3	8	0.4	0.028	0.33	473	
207	Explosive, nitro-glycerine (Chester's); ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 100 feet; case, can No. 1, open; ignition, Smith's battery. 2 Mowbray fuzes. Effects: Bubbling began in 6½ seconds after explosion.	1	1	0.4	0.092	26.82	8,841	
		1	2	0.4	0.100	29.55	9,552	
		1	3	0.4	0.103	30.85	9,816	
		1	4	0.4	0.093	26.69	8,925	
		1	5	0.4	0.085	23.69	8,244	
		1	6	0.4	0.100	29.55	9,552	
		3	7	0.4	0.107	1.94	1,550	
		3	8	0.4	0.045	0.62	727	
208	Explosive, nitro-glycerine (Chester's); ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 100 feet; case, can No. 2, open; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Both fuzes failed on first trial; replaced then by new ones; bubbling began in 5½ seconds after explosion; found suspension ring cracked.	1	1	0.4	0.228	99.94	21,522	
		1	2	0.4	0.237	106.60	22,465	
		1	3	0.4	0.257	122.10	24,600	
		1	4	0.4	0.268	131.20	25,804	
		1	5	0.4	0.205	83.84	19,145	
		1	6	0.4	0.214	89.84	20,044	
		3	7	0.4	0.097	1.69	1,422	
		3	8	0.4	0.106	1.91	1,536	
209	Explosive, dynamite No. 1, made on spot; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 100 feet; case, fuze can, compacted; ignition, Smith's battery, 2 Mowbray fuzes. Made from the Chester nitro-glycerine, for direct comparison. Effects: Bubbling began 12½ seconds after explosion.	1	1	0.4	0.085	23.69	8,244	
		1	2	0.4	0.070	18.42	6,971	
		1	3	0.4	0.070	18.42	6,971	
		1	4	0.4	0.079	21.58	7,745	
		1	5	0.4	0.064	16.42	6,453	
		1	6	0.4	0.066	17.07	6,624	
		3	7	0.4	6.028	0.33	473	
		3	8	0.4	0.023	0.26	404	
210	Explosive, dynamite No. 2; ring 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 100 feet: case, fuze can; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Bubbling began 19 seconds after explosion.	1	1	0.4	0.037	8.24	4,080	
		1	2	0.4	0.043	9.91	4,608	
		1	3	0.4	0.038	8 53	4,172	
		1	4	0.4	0.035	7.67	3,896	
		1	5	0.4	0.036	7.96	3,988	
		1	6	0.4	0.037	8.24	4,080	
		3	7	0.4	0.007	0.06	156	
		3	8	0.4	0.018	0.19	335	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
211	Explosive, dynamite No. 1, made on spot; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 110 feet; case, can No. 1; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Bubbling began 10 seconds after explosion.	1	1	0.4	0.217	92.01	20,366	
		1	2	0.4	0.209	86.37	19,525	
		1	3	0.4	0.124	39.95	11,677	
		1	4	0.4	0.124	39.95	11,677	
		1	5	0.4	0.128	41.70	12,018	
		1	6	0.4	0.109	38.22	10,828	
		3	7	0.4	0.065	1.01	1,006	
		3	8	0.4	0.034	0.42	563	
212	Explosive, dynamite No. 2; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 100 feet; case, can No. 2; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Bubbling began 6 seconds after explosion.	1	1	0.4	0.238	......	......	Defective lead.
		1	2	0.4	0.192	75.47	17,847	
		1	3	0.4	0.146	50.42	13,678	
		1	4	0.4	0.133	44.14	12,479	
		1	5	0.4	0.107	32.42	10,160	
		1	6	0.4	0.115	35.82	10,857	
		3	7	0.4	0.076	1.22	1,142	
		3	8	0.4	0.051	0.73	808	
213	Explosive, dynamite No. 1, made on spot; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 100 feet; case, can No. 2; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Failed to explode at 15 turns of battery, went at 20 turns; bubbling appeared 6 seconds after explosion.	1	1	0.4	0.252	118.10	24,056	
		1	2	0.4	0.258	123.00	24,710	
		1	3	0.4	0.148	51.08	13,859	
		1	4	0.4	0.148	51.03	13,859	
		1	5	0.4	0.159	57.35	14,862	
		1	6	0.4	0.137	46.18	12,851	
		3	7	0.4	0.071	1.12	1,078	
		3	8	0.4	0.066	1.08	1,018	
214	Explosive, dynamite No. 1, made on spot; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 110 feet; case, can No. 2; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Bubbling in 4 seconds after explosion.	1	1	0.4	0.207	85.10	19,335	
		1	2	0.4	0.190	74.30	17,665	
		1	3	0.4	0.195	77.22	18,120	
		1	4	0.4	0.206	84.47	19,240	
		1	5	0.4	0.198	76.05	17,998	
		1	6	0.4	0.200	80.46	18,625	
		3	7	0.4	0.130	2.55	1,865	
		3	8	0.4	0.083	1.38	1,239	
215	Explosive, nitro-glycerine (Chester's); ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 100 feet; case, can No. 2, open; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Normal.	1	1	0.4	0.120	38.05	11,305	
		1	2	0.4	0.150	52.64	14,040	
		1	3	0.4	0.167	61.50	15,569	
		1	4	0.4	0.187	72.63	17,398	
		1	5	0.4	0.174	65.26	16,199	
		1	6	0.4	0.150	52.64	14,040	
		3	7	0.4	0.130	2.55	1,865	
		3	8	0.4	0.085	1.43	1,268	
216	Explosive, dynamite No. 1, made on spot; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 100 feet; case, can No. 2; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Dome 2 feet high rose in 4 seconds after explosion.	1	1	0.4	0.278	139.60	26,892	
		1	2	0.4	0.208	82.48	18,987	
		1	3	0.4	0.247	114.20	23,531	
		1	4	0.4	0.257	122.10	24,600	
		1	5	0.4	0.234	104.40	22,150	
		1	6	0.4	0.242	110.40	22,898	
		3	7	0.4	0.102	1.81	1,486	
		3	8	0.4	0.188	2.77	1,971	
217	Fired in the Crate.—See Appendix B.							
218	Fired in the Crate.—See Appendix B.							

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
219	Explosive, nitro-glycerine (Chester's); ring, 3 foot; charge, 1½ pounds; submergence, 35 feet; depth of water, 110 feet; case, fuze can, open; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Normal.	1	1	0.4	0.170	63.10	15,837	
		1	2	0.4	0.165	60.43	15,390	
		1	3	0.4	0.140	47.52	13,118	
		1	4	0.4	0.151	53.14	14,128	
		1	5	0.4	0.116	36.27	10,947	
		1	6	0.4	0.148	51.03	13,859	
		3	7	0.4	0.042	0.57	683	
		3	8	0.4	0.056	0.82	874	
220	Explosive, nitro-glycerine (Chester's); ring, 3 foot; charge, 1 pound; submergence, 35 feet; depth of water, 110 feet; case, glass bottle, open; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Broke new suspension strap.	1	1	0.4	0.102	30.42	9,728	
		1	2	0.4	0.110	33.62	10,412	
		1	3	0.4	0.110	33.62	10,412	
		1	4	0.4	0.106	32.01	10,076	
		1	5	0.4	0.081	22.31	7,918	
		1	6	0.4	0.128	41.70	12,018	
		3	7	0.4	0.025	0.29	438	
		3	8	0.4	0.032	0.39	529	
221	Explosive, nitro-glycerine (Chester's); ring, 3 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 110 feet; case, glass bottle; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Normal; charge rather low in ring.	1	1	0.4	0.113	34.94	10,679	
		1	2	0.4	0.126	40.85	11,853	
		1	3	0.4	0.118	37.16	11,126	
		1	4	0.4	0.138	46.50	12,939	
		1	5	0.4	0.148	51.03	13,859	
		1	6	0.4	0.150	52.64	14,040	
		3	7	0.4	0.083	1.38	1,239	
		3	8	0.4	0.051	0.73	808	
222	Explosive, nitro-glycerine (Chester's); ring, 3 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 110 feet; case, glass bottle; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Broke lowering rope.	1	1	0.4	0.225	97.75	21,210	
		1	2	0.4	0.187	72.63	17,398	
		1	3	0.4	0.194	76.64	18,029	
		1	4	0.4	0.196	77.87	18,221	
		1	5	0.4	0.152	53.64	14,216	
		1	6	0.4	0.159	57.35	14,862	
		3	7	0.4	0.122	2.32	1,750	
		3	8	0.4	0.065	1.01	1,006	
223	Explosive, musket powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 70 feet; case, 24-gallon keg diaphragmed, air space down; ignition, Smith's battery, 2 Browne No. 4 glycerine fuzes. Effects: Normal.	1	1	0.4	0.082	8.38	4,121	
		1	2	0.4	0.077	7.70	3,986	
		1	3	0.4	0.099	10.76	4,871	
		1	4	0.4	0.092	9.73	4,554	
		1	5	0.4	0.088	9.17	4,377	
		1	6	0.4	0.178	24.95	8,532	
		3	7	0.4	0.032	0.019	69	
		3	8	0.4	0.038	0.023	81	
224	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 2, saw-dust tamping; ignition, Smith's battery, 1 Browne No. 4, glycerine fuze. Effects: Normal.	1	1	0.4	0.245	112.70	23,325	
		1	2	0.4	0.260	124.60	24,930	
		1	3	0.4	0.225	97.75	21,210	
		1	4	0.4	0.242	110.40	22,898	
		1	5	0.4	0.236	105.80	22,360	
		1	6	0.4	0.225	97.75	21,210	
225	Fired in the Crate.—See Appendix B.	3	7	0.4	0.067	1.05	1,030	
226	Fired in the Crate.—See Appendix B.	3	8	0.4	0.033	0.40	540	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
227	Explosive, gun-cotton; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 94 feet; case, can No. 1, sawdust tamped; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	1	1	0.4	0.064	16.42	6,458	
		1	2	0.4	0.068	17.74	6,797	
		1	3	0.4	0.058	14.49	5,938	
		1	4	0.4	0.047	11.08	4,952	
		1	5	0.4	0.059	14.82	6,028	
		1	6	0.4	0.070	18.42	6,971	
		3	7	0.4	0.017	0.19	325	
		3	8	0.4	0.023	0.26	404	
228	Explosive, gun-cotton; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 94 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	1	1	0.4	0.112	34.50	10,590	
		1	2	0.4	0.150	52.64	14.040	
		1	3	0.4	0.115	35.82	10,857	
		1	4	0.4	0.135	45.20	12,677	
		1	5	0.4	0.117	36.71	11,036	
		1	6	0.4	0.114	35.38	10,768	
		3	7	0.4	0.060	0.89	925	
		3	8	0.4	0.042	0.57	683	
229	Explosive, gun-cotton; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 94 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Normal.	1	1	0.4	0.157	56.25	14,671	
		1	2	0.4	0.205	83.84	19,145	
		1	3	0.4	0.146	50.42	13,678	
		1	4	0.4	0.165	60.43	15,390	
		1	5	0.4	0.136	45.66	12,764	
		1	6	0.4	0.153	54.15	14,304	
		3	7	0.4	0.035	0.44	578	
		3	8	0.4	0.044	0.60	713	
230	Explosive, gun-cotton; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 94 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Abel fuze. Effects: Normal. Two failures followed from bad (Abel) fuzes.	1	1	0.4	0.202	81.81	18,833	
		1	2	0.4	0.225	97.75	21,210	
		1	3	0.4	0.172	64.18	16,018	
		1	4	0.4	0.162	58.91	15,130	
		1	5	0.4	0.160	57.90	14,957	
		1	6	0.4	0.167	61.50	15,569	
		3	7	0.4	0.080	1.31	1,196	
		3	8	0.4	0.050	0.71	795	
231	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 94 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal.	1	1	0.4	0.172	64.18	16,018	
		1	2	0.4	0.225	97.75	21,210	
		1	3	0.4	0.200	80.46	18,625	
		1	4	0.4	0.175	65.80	16,290	
		1	5	0.4	0.159	57.35	14,862	
		1	6	0.4	0.178	67.52	16,570	
		3	7	0.4	0.027	0.31	461	
		3	8	0.4	0.053	0.76	834	
232	Explosive, dualin, compacted; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 88 feet; case, fuze can, full; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal.	1	1	0.4	0.121	38.52	11,398	
		1	2	0.4	0.094	27.07	9,009	
		1	3	0.4	0.088	24.82	8,502	
		1	4	0.4	0.076	20.46	7,473	
		1	5	0.4	0.074	19.75	7,300	
		1	6	0.4	0.083	23.00	8,080	
		3	7	0.4	0.018	0.19	335	
		3	8	0.4	0.033	0.40	545	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
233	Explosive, dualin, compacted; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 88 feet; case, can No. 1, sawdust tamped; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal.	1	1	0.4	0.140	47.52	13,113	
		1	2	0.4	0.172	64.18	16,018	
		1	3	0.4	0.126	40.85	11,853	
		1	4	0.4	0.155	55.15	14,480	
		1	5	0.4	0.124	39.95	11,677	
		1	6	0.4	0.113	34.94	10,679	
		3	7	0.4	0.092	1.57	1,351	
		3	8	0.4	0.045	0.62	727	
234	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 88 feet; case, can No. 1, full; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Broke a gib to suspension strap.	1	1	0.4	0.179	68.10	16,664	
		1	2	0.4	0.187	72.63	17,398	
		1	3	0.4	0.183	70.38	17,035	
		1	4	0.4	0.173	64.72	16,109	
		1	5	0.4	0.142	48.56	13,308	
		1	6	0.4	0.160	57.90	14,957	
		3	7	0.4	0.093	1.60	1,365	
		3	8	0.4	0.057	0.84	887	
235	Explosive, O. P. Co. compound; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 88 feet; case, can No. 2, sawdust tamped; ignition, Smith's battery, 2 Browne No. 4 fuzes. Effects: Compound had been on hand a year; it was dark and covered with mould; no jet or dome, only a boiling of water.	1	1	0.4	0.060	15.15	6,119	
		1	2	0.4	0.060	15.15	6,119	
		1	3	0.4	0.044	10.18	4,692	
		1	4	0.4	0.032	6.88	3,617	
		1	5	0.4	0.034	7.41	3,808	
		1	6	0.4	0.032	6.88	3,617	
		3	7	0.4	0.033	0.25	545	
		3	8	0.4	0.032	0.24	529	
236	Explosive, dualin, compacted; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 88 feet; case, can No. 2, sawdust tamped; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Suspension strap showed signs of yielding.	1	1	0.4	0.242	110.40	22,898	
		1	2	0.4	0.182	69.81	16,942	
		1	3	0.4	0.212	88.42	19,832	
		1	4	0.4	0.190	74.30	17,665	
		1	5	0.4	0.207	85.10	19,335	
		1	6	0.4	0.203	82.48	18,987	
		3	7	0.4	0.073	1.16	1,103	
		3	8	0.4	0.105	1.88	1,522	
237	Explosive, nitro-glycerine (Chester's); ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 90 feet; case, can No. 1, open; ignition, Smith's battery, 2 Mowbray fuzes. Effects: Fuzes failed at 20 turns of the battery and exploded at 25 turns, giving a 2-inch spark; the explosive had been on hand for 50 days and had deteriorated, showing acid.	1	1	0.4	0.081	22.31	7,918	
		1	2	0.4	0.108	.....	......	Defective lead.
		1	3	0.4	0.057	14.16	5,847	
		1	4	0.4	0.044	10.18	4,692	
		1	5	0.4	0.068	17.74	6,797	
		1	6	0.4	0.064	16.42	6,453	
		3	7	0.4	0.075	1.20	1,129	
		3	8	0.4	0.035	0.44	578	
238	Explosive, nitro-glycerine (Chester's); ring, 4 foot; charge, $3\frac{11}{16}$ pounds; submergence, 35 feet; depth of water, 90 feet; case, can No. 2, open; ignition, Smith's battery, 1 Mowbray and 1 Browne No. 4 fuze. Effects: Two Mowbray fuzes had failed to explode; this charge did not equal normal effect by reason of bad quality of the nitro-glycerine.	1	1	0.4	0.063	16.10	6,370	
		1	2	0.4	0.096	.....	......	Oblique lead.
		1	3	0.4	0.057	14.16	5,847	
		1	4	0.4	0.071	18.75	7,053	
		1	5	0.4	0.065	16.73	6,537	
		1	6	0.4	0.066	17.07	6,624	
		3	7	0.4	0.043	0.58	698	
		3	8	0.4	0.023	0.26	404	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
239	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 17 feet; case, can No 1; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Ring hung from crane on wharf; jet 30 feet high.	1	1	0.4	0.204	83.16	19,041	
		1	2	0.4	0.194	76.64	18,029	
		1	3	0.4	0.202	81.81	18,833	
		1	4	0.4	0.289	.....	......	Double pin mark.
		1	5	0.4	0.210	87.00	19,620	
		1	6	0.4	0.254	.....	......	Lengthened mark.
240	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 17 feet; case, can No. 1; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Fired from wharf; normal.	1	1	0.4	0.207	85.10	19,335	
		1	2	0.4	0.217	92.01	20,366	
		1	3	0.4	0.198	79.16	18,423	
		1	4	0.4	0.174	65.26	16,199	
		1	5	0.4	0.132	43.62	12,381	
		1	6	0.4	0.170	63.10	15,837	
241	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 17 feet; case, can No. 1; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Fired from wharf; normal.	1	1	0.3	0.243	70.16	17,002	
		1	2	0.3	0.277	87.60	19,713	
		1	3	0.3	0.222	60.28	15,367	
		1	4	0.3	0.275	86.48	19,545	
		1	5	0.3	0.231	64.24	16,082	
		1	6	0.3	0.234	65.77	16,285	
242	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 17 feet; case, can No. 1; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Fired from wharf; normal.	3	1	0.75	0.465	86.98	19,620	
		3	2	0.75	.....	.....	......	Defective lead.
		3	3	0.75	0.467	87.66	19,720	
		3	4	0.75	0.590	138.50	26,755	
		3	5	0.75	0.366	56.43	14,728	
		3	6	0.75	0.481	92.53	20,444	
243	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 15 feet; case, can No. 1; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Fired from wharf; normal.	2	1	0.75	0.202	60.25	15,358	
		2	2	0.75	0.194	56.71	14,750	
		2	3	0.75	0.201	59.84	15,289	
		2	4	0.75	0.203	60.66	15,427	
		2	5	0.75	0.166	45.67	12,748	
		2	6	0.75	0.132	32.68	10,216	
244	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 16 feet; case, can No. 1; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Fired from wharf; normal.	2	1	0.75	0.182	51.67	13,867	
		2	2	0.75	0.220	67.70	16,600	
		2	3	0.75	0.232	73.02	17,460	
		2	4	0.75	0.246	79.54	18,480	
		2	5	0.75	0.321	118.90	24,165	
		2	6	0.75	0.201	59.84	15,289	
245	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 17 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	1	1	0.6	0.365	73.33	17,027	
		1	2	0.6	0.480	113.00	23,360	
		1	3	0.6	0.359	71.50	17,237	
		1	4	0.6	0.364	73.02	17,474	
		1	5	0.6	0.255	42.30	12,137	
		1	6	0.6	0.274	47.00	13,015	
246	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 16 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	2	1	0.6	0.388	80.51	18,138	
		2	2	0.6	0.351	69.01	16,817	
		2	3	0.6	0.387	80.19	18,090	
		2	4	0.6	0.414	89.42	20,022	
		2	5	0.6	0.324	60.82	15,455	
		2	6	0.6	0.296	52.91	14,084	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
247	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 16 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	2	1	0.5	0.508	72.58	17,390	
		2	2	0.5	0.619	107.50	22,600	
		2	3	0.5	0.464	62.34	15,723	
		2	4	0.5	0.585	96.83	21,075	
		2	5	0.5	0.423	52.86	14,075	
		2	6	0.5	0.491	68.58	16,744	
248	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 16 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	2	1	0.5	0.463	62.11	15,675	
		2	2	0.5	0.515	74.48	17,688	
		2	3	0.5	0.573	91.14	20,240	
		2	4	0.5	0.482	66.43	16,397	
		2	5	0.5	0.474	64.60	16,070	
		2	5	0.5	0.349	38.13	11,321	
249	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 16 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	1	1	0.75	0.064	81.00	18,705	
		1	2	0.75	0.059	72.33	17,347	
		1	3	0.75	0.077	102.32	21,857	
		1	4	0.75	0.086	117.40	23,961	
		1	5	0.75	0.047	53.62	14,192	
		1	6	0.75	0.082	110.70	23,035	
250	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 16 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	1	1	0.75	0.084	114.10	23,505	
		1	2	0.75	0.051	59.53	15,209	
		1	3	0.75	0.092	.....	......	Two pin marks.
		1	4	0.75	0.100	.....	......	Lengthened pin mark.
		1	5	0.75	0.051	59.53	15,209	
		1	6	0.75	0.075	99.00	21,385	
251	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds, submergence, 6 feet; depth of water, 16 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	1	1	0.6	0.094	63.29	15,834	
		1	2	0.6	0.067	40.23	11,728	
		1	3	0.6	0.100	68.73	16,770	
		1	4	0.6	0.122	89.88	20,050	
		1	5	0.6	0.083	53.51	14,189	
		1	6	0.6	0.090	59.51	15,237	
252	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 15 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	1	1	0.6	0.092	60.90	15,535	
		1	2	0.6	0.118	85.82	19,437	
		1	3	0.6	0.118	85.82	19,437	
		1	4	0.6	0.120	87.80	19,740	
		1	5	0.6	0.080	50.91	13,727	
		1	6	0.6	0.084	54.38	14,343	
253	Explosive, nitro-glycerine (Chester's); ring, 4 foot, charge, $2\frac{3}{16}$ pounds; submergence, 6 feet; depth of water, 13 feet; case, can No. 1, open; ignition, Smith's battery, 1 Browne No. 4 dualin fuze. Effects: Fuze burst open can, but failed to explode the nitro-glycerine, which had deteriorated since its receipt two months before.	1	1	0.4	.....	.....	......	
		1	2	0.4	.....	.....	......	
		1	3	0.4	.....	.....	......	
		1	4	0.4	.....	.....	......	
		1	5	0.4	.....	.....	......	
		1	6	0.4	.....	.....	......	
254	Explosive, nitro-glycerine (Chester's); ring, 4 foot; charge, $2\frac{3}{16}$ pounds; submergence, 6 feet; depth of water, 13 feet; case, can No. 1, open; ignition, Smith's battery, 1 Mowbray fuze. Effects: Unusually little. Fired from wharf.	1	1	0.4	0.054	13.21	5,576	
		1	2	0.4	0.042	9.64	4,524	
		1	3	0.4	0.080	21.96	7,836	
		1	4	0.4	0.053	12.91	5,486	
		1	5	0.4	0.120	38.05	11,305	
		1	6	0.4	0.089	25.19	8,588	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
255	Explosive, dynamite No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 80 feet; case, fuze can; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal. This charge consisted of 9 ounces made at Willets Point, with extra per cent. of nitroglycerine, and 7 ounces made in California.	1	1	0.4	0.185	71.52	17,220	
		1	2	0.4	0.132	43.62	12,381	
		1	3	0.4	0.081	22.31	7,918	
		1	4	0.4	0.092	26.32	8,841	
		1	5	0.4	0.063	16.10	6,370	
		1	6	0.4	0.074	19.75	7,300	
		3	7	0.4	0.039	0.51	639	
		3	8	0.4	0.033	0.40	545	
256	Explosive, dualin, compacted; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 80 feet; case, can No. 2, sawdust tamped; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Lowering rope parted by explosion, letting ring down.	1	1	0.4	0.259	123.80	24,820	
		1	2	0.4	0.230	101.40	21,730	
		1	3	0.4	0.230	101.40	21,730	
		1	4	0.4	0.252	118.10	24,056	
		1	5	0.4	0.160	57.90	14,957	
		1	6	0.4	0.176	66.37	16,383	
		3	7	0.4	0.106	1.91	1,536	
		3	8	0.4	0.090	1.52	1,321	
257	Explosive, gun-cotton; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 80 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 dualin fuze. Effects: Third trial, two Abel gun-cotton fuzes having failed in succession. Explosion broke mooring-rope and let ring down.	1	1	0.4	0.245	112.70	23,325	
		1	2	0.4	0.209	86.37	19,525	
		1	3	0.4	0.232	102.90	21,940	
		1	4	0.4	0.181	69.24	16,850	
		1	5	0.4	0.166	60.96	15,479	
		1	6	0.4	0.170	63.10	15,837	
		3	7	0.4	0.094	1.62	1,380	
		3	8	0.4	0.062	0.94	957	
258	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 16 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf; charge a litle damp.	1	1	0.4	0.138	46.59	12,939	
		1	2	0.4	0.181	69.24	16,850	
		1	3	0.4	0.168	62.03	15,658	
		1	4	0.4	0.172	64.18	16,018	
		1	5	0.4	0.195	77.22	18,120	
		1	6	0.4	0.182	69.81	16,942	
259	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 16 feet; case, can No. 1, sawdust tamped; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Buffer broke, which let ring down.	1	1	0.3	0.241	69.19	16,844	
		1	2	0.3	0.231	64.24	16,032	
		1	3	0.3	0.280	89.80	20,041	
		1	4	0.3	0.268	83.00	19,018	
		1	5	0.3	0.235	66.28	16,370	
		1	6	0.3	0.275	86.48	19,545	
260	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 0 feet; depth of water, 16 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Loud report; jet 150 feet high; fragments of tin can indented the ring; fired from wharf; suspended by crane.	1	1	0.3	0.145	31.18	9,902	In air.
		1	2	0.3	0.045	6.40	3,445	Do.
		1	3	0.3	0.080	13.71	5,725	Surface.
		1	4	0.3	0.094	17.04	6,615	Do.
		1	5	0.3	0.255	76.14	17,950	2 feet down.
		1	6	0.3	0.167	38.81	11,453	Do.
261	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 15 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	1	1	0.5	0.123	50.86	13,716	
		1	2	0.5	0.126	52.65	14,037	
		1	3	0.5	0.163	77.02	18,089	
		1	4	0.5	0.192	98.54	21,316	Lead dented.
		1	5	0.5	0.128	53.83	14,245	
		1	6	0.5	0.158	73.51	17,536	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
262	Explosive, dualin, compacted; ring, 4 foot; charge, 3 pounds; submergence, 6 feet; depth of water, 15 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	1	1	0.5	0.160	74.95	17,765	
		1	2	0.5	0.143	63.25	15,873	
		1	3	0.5	0.167	79.80	18,521	
		1	4	0.5	0.168	80.49	18,629	
		1	5	0.5	0.099	37.32	11,162	
		1	6	0.5	.....	......	......	Lead defective.
263	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 14 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Fired from wharf; jet 20 to 30 feet high.	1	1	0.5	0.035	9.88	4,601	
		1	2	0.5	0.044	13.19	5,577	
		1	3	0.5	0.030	8.24	4,076	
		1	4	0.5	0.051	15.66	6,253	
		1	5	0.5	0.022	5.82	3,228	
		1	6	0.5	0.026	7.01	3,658	
264	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 15 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	1	1	0.5	0.027	7.32	3,762	
		1	2	0.5	0.049	14.93	6,058	
		1	3	0.5	0.035	9.88	4,601	
		1	4	0.5	0.044	13.19	5,577	
		1	5	0.5	0.036	10.26	4,716	
		1	6	0.5	0.044	13.19	5,577	
265	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 15 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	1	1	0.4	0.034	7.41	3,803	
		1	2	0.4	0.057	14.16	5,847	
		1	3	0.4	0.048	11.39	5,039	
		1	4	0.4	0.063	16.10	6,370	
		1	5	0.4	0.053	12.91	5,486	
		1	6	0.4	0.053	12.91	5,486	
266	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 foot; depth of water, 15 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	1	1	0.4	0.046	10.76	4,864	
		1	2	0.4	0.048	11.39	5,039	
		1	3	0.4	0.048	11.39	5,039	
		1	4	0.4	0.055	13.50	5,666	
		1	5	0.4	0.064	16.42	6,453	
		I	6	0.4	0.059	14.82	6,028	
267	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 16 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	1	1	0.3	0.075	12.52	5,389	
		1	2	0.3	0.080	13.71	5,725	
		1	3	0.3	0.050	7.31	3,764	
		1	4	0.3	0.087	15.31	6,159	
		1	5	0.3	0.058	9.01	4,325	
		1	6	0.3	0.067	10.80	4,880	
268	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 foot; depth of water, 16 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	1	1	0.3	0.067	10.80	4,880	
		1	2	0.3	0.084	14.59	5,967	
		1	3	0.3	0.060	9.54	4,495	
		1	4	0.3	0.068	11.00	4,943	
		1	5	0.3	0.060	9 54	4,495	
		1	6	0.3	0.072	11.86	5,197	
269	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 16 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.75	0.117	10.77	4,869	
		3	2	0.75	0.148	14.77	6,016	
		3	3	0.75	0.142	13.96	5,792	
		3	4	0.75	0.154	15.64	6,249	
		3	5	0.75	0.094	8.04	4,009	
		3	6	0.75	0.106	9.45	4,467	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
270	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 16 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.75	0.111	10.05	4,656	
		3	2	0.75	0.144	14.20	5,861	
		3	3	0.75	0.120	11.17	4,981	
		3	4	0.75	0.117	10.77	4,869	
		3	5	0.75	0.087	7.28	3,753	
		3	6	0.75	0.093	7.93	3,972	
271	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 16 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.6	0.215	12.21	5,250	
		3	2	0.6	0.227	13.33	5,619	
		3	3	0.6	0.195	10.57	4,814	
		3	4	0.6	0.183	9.59	4,511	
		3	5	0.6	0.166	8.34	4,110	
		3	6	0.6	0.156	7.64	3,876	
272	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 16 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.6	0.209	11.65	5,136	
		3	2	0.6	0.204	11.30	5,032	
		3	3	0.6	0.212	11.92	5,194	
		3	4	0.6	0.179	9.29	4,415	
		3	5	0.6	0.162	8.06	4,017	
		3	6	0.6	0.167	8.41	4,133	
273	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 15 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.5	0.301	11.64	5,132	
		3	2	0.5	0.363	15.39	6,183	
		3	3	0.5	0.281	10.47	4,783	
		3	4	0.5	0.317	12.57	5,403	
		3	5	0.5	0.222	7.32	3,767	
		3	6	0.5	0.214	6.96	3,636	
274	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 15 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.5	0.344	14.18	5,855	
		3	2	0.5	0.335	13.64	5,705	
		3	3	0.5	0.273	10.02	4,648	
		3	4	0.5	0.235	7.96	3,984	
		3	5	0.5	0.293	11.12	4,981	
		3	6	0.5	0.234	7.92	3,969	
275	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 14 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.4	0.481	23.11	8,110	
		3	2	0.4	0.420	17.89	6,836	
		3	3	0.4	0.380	14.70	5,996	
		3	4	0.4	0.332	11.42	5,066	
		3	5	0.4	0.260	7.48	3,822	
		3	6	0.4	0.335	11.59	5,118	
276	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 11 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.4	0.376	14.42	5,919	
		3	2	0.4	0.360	13.26	5,599	
		3	3	0.4	0.357	13.06	5,543	
		3	4	0.4	0.343	12.09	5,265	
		3	5	0.4	0.310	10.10	4,670	
		3	6	0.4	0.302	9.67	4,535	
277	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 12 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.75	0.153	15.50	6,211	
		3	2	0.75	0.138	13.45	5,651	
		3	3	0.75	0.111	10.05	4,656	
		3	4	0.75	0.123	11.54	5,097	
		3	5	0.75	0.069	5.42	3,082	
		3	6	0.75	0.093	7.93	3,972	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
278	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 12 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	2	1	0.75	0.076	15.76	6,278	
		2	2	0.75	0.052	9.83	4,582	
		1	3	0.4	0.048	11.39	5,039	
		3	4	0.75	0.101	8.84	4,278	
		2	5	0.75	0.037	6.41	3,452	
		2	6	0.75	0.037	6.41	3,452	
279	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 13 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	2	1	0.75	0.109	25.33	8,618	
		2	2	0.75	0.051	9.59	4,508	
		1	3	0.4	0.045	10.45	4,776	
		3	4	0.75	0.099	8.61	3,197	
		2	5	0.75	0.042	7.52	3,845	
		2	6	0.75	0.049	9.12	4,361	
280	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 13 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	2	1	0.75	0.050	9.85	4,435	
		3	2	0.75	0.120	11.17	4,981	
		1	3	0.4	0.048	11.39	5,039	
		2	4	0.75	0.040	7.06	3,697	
		2	5	0.75	0.042	7.52	3,845	
		3	6	0.75	0.099	9.12	3,197	
281	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 13 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuse. Effects: Normal; fired from wharf.	2	1	0.6	0.095	10.53	4,796	
		3	2	0.6	0.202	11.16	4,991	
		1	3	0.4	0.053	12.91	5,486	
		2	4	0.6	0.060	5.80	3,226	
		2	5	0.6	0.081	8.54	4,174	
		3	6	0.6	0.152	7.36	3,781	
282	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 13 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.6	0.205	11.37	5,053	
		2	2	0.6	0.055	5.19	2,991	
		1	3	0.4	0.050	12.03	5,215	
		3	4	0.6	0.147	7.01	3,659	
		2	5	0.6	0.057	5.44	3,085	
		3	6	0.6	0.139	6.45	2,463	
283	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 14 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.6	0.213	12.02	5,213	
		2	2	0.6	0.054	5.07	2,945	
		1	3	0.4	0.057	14.16	5,847	
		3	4	0.6	0.186	9.83	4,583	
		2	5	0.6	0.077	8.00	3,997	
		3	6	0.6	0.164	8.20	4,063	
284	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 14 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.5	0.312	12.28	5,339	
		2	2	0.5	0.098	5.55	3,183	
		1	3	0.4	0.045	10.45	4,776	
		3	4	0.5	0.223	7.36	3,783	
		2	5	0.5	0.086	4.99	2,918	
		3	6	0.5	0.200	6.31	3,412	
285	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 14 feet; case, fuze-can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.4	0.389	15.41	6,189	
		3	2	0.4	0.373	14.56	5,862	
		1	3	0.4	......	......	......	Spoiled.
		3	4	0.4	0.330	11.30	5,032	
		3	5	0.4	0.298	9.44	4,464	
		3	6	0.4	0.310	10.10	4,670	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
286	Explosive, dynamite No. 1, loose; ring 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 17 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.5	0.307	11.96	5,227	
		3	2	0.5	0.324	12.98	5,518	
		1	3	0.3	.....	.....	......	Failed.
		2	4	0.5	0.132	8.97	4,312	
		3	5	0.5	0.207	6.60	3,518	
		3	6	0.5	0.229	7.68	3,891	
287	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 17 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.6	0.172	8.77	4,249	
		3	2	0.6	0.142	6.66	3,536	
		1	3	0.3	.....	.....	......	Failed.
		2	4	0.4	0.180	10.75	4,869	
		3	5	0.6	0.129	5.80	3,226	
		3	6	0.6	0.149	7.15	3,709	
288	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 17 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.6	0.219	12.61	5,324	
		3	2	0.6	0.192	10.31	4,733	
		1	3	0.3	0.045	6.40	3,445	
		2	4	0.4	0.168	9.73	4,552	
		3	5	0.6	0.148	7.08	3,684	
		3	6	0.6	0.133	6.06	3,320	
289	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 17 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.6	0.198	10.84	4,895	
		3	2	0.6	0.199	10.93	4,922	
		1	3	0.3	.....	.....	......	Failed.
		2	4	0.4	0.195	12.13	5,277	
		3	5	0.6	0.163	8.13	4,040	
		3	6	0.6	0.140	6.52	3,487	
290	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 17 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.75	0.136	13.19	5,578	
		3	2	0.75	0.082	6.76	3,570	
		1	3	0.3	0.048	6.95	3.636	
		2	4	0.3	0.246	11.09	4,969	
		3	5	0.75	0.069	5.42	3,082	
		3	6	0.75	0.089	7.49	3,824	
291	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 17 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf.	3	1	0.75	0.125	11.78	5,175	
		3	2	0.6	0.159	16.39	6,448	
		1	3	0.3	0.052	7.67	3,887	
		2	4	0.3	0.243	10.86	4,901	
		3	5	0.75	0.079	6.44	3,454	
		3	6	0.75	0.082	6.76	3,570	
292	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, ½ pound; submergence, 6 feet; depth of water, 16 feet; case, fuze can, sawdust tamping: ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal; fired from wharf. Discontinued use of gauge pattern No. 2 after this date (November 13, 1872), which was end of the season, except 1 crate shot.	3	1	0.75	0.093	7.93	3,972	
		3	2	0.75	0.119	11.03	4,944	
		1	3	0.3	0.050	7.31	3,764	
		2	4	0.3	0.240	10.63	4,832	
		3	5	0.75	0.076	6.09	3,333	
		3	6	0.75	0.075	5.98	3,292	
293	Fired in Crate.—See Appendix B.							
294	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 5 pounds; submergence, 100 feet; depth of water, 115 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Fired under wooden raft; a few bubbles rose long after explosion; fish jumping from water at great distances; no jet. First shot of season (June 5, 1873).	1	1	0.4	0.278	139.60	26,892	
		1	2	0.4	0.267	130.40	25,701	
		1	3	0.4	0.190	74.30	17,665	
		1	4	0.4	0.194	76.64	18,029	
		1	5	0.4	0.160	57.90	14,957	
		1	6	0.4	0.078	21.21	7,654	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
295	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 5 pounds; submergence, 80 feet; depth of water, 115 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Suspended under wooden target; bubbles appeared long after explosion; no jet.	1	1	0.4	0.290	149.80	28,190	
		1	2	0.4	.....	......	......	Spoiled.
		1	3	0.4	0.195	77.22	18,120	
		1	4	0.4	0.199	79.81	18,524	
		1	5	0.4	0.235	105.10	22,255	
		1	6	0.4	.....	......	......	Spoiled.
296	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 5 pounds; submergence, 70 feet; depth of water, 120 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Suspended under wooden target; no jet; many fish killed.	1	1	0.4	0.191	74.88	17,756	
		1	2	0.4	0.175	65.80	16,290	
		1	3	0.4	0.243	111.10	23,007	
		1	4	0.4	0.200	80.46	18,625	
		1	5	0.4	0.253	118.90	24,164	
		1	6	0.4	0.206	84.47	19,240	
297	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 5 pounds; submergence, 60 feet; depth of water, 120 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Suspended under wooden target; upward boiling of water appeared in 20 seconds after explosion.	1	1	0.4	0.234	104.40	22,150	
		1	2	0.4	0.249	115.70	23,737	
		1	3	0.4	0.218	92.74	20,474	
		1	4	0.4	0.247	114.20	23,531	
		1	5	0.4	0.130	42.56	12,183	
		1	6	0.4	0.199	79.81	18,524	
298	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 5 pounds; submergence, 50 feet; depth of water, 120 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Suspended under wooden target; boiling appeared in 20 seconds after firing.	1	1	0.4	0.262	126.30	25,156	
		1	2	0.4	.....	......	......	Spoiled.
		1	3	0.4	0.212	88.42	19,832	
		1	4	0.4	0.203	82.48	18,937	
		1	5	0.4	0.151	53.14	14,128	
		1	6	0.4	0.150	52.64	14,040	
299	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 5 pounds; submergence, 40 feet; depth of water, 120 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Suspended under wooden target; boiling appeared at surface in 5 seconds after firing.	1	1	0.4	.....	......	......	Spoiled.
		1	2	0.4	0.299	157.70	29,193	
		1	3	0.4	0.207	85.10	19,335	
		1	4	0.4	0.214	89.84	20,044	
		1	5	0.4	0.200	80.46	18,625	
		1	6	0.4	0.181	69.24	16,850	
300	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 5 pounds; submergence, 32 feet; depth of water, 120 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Suspended from wooden target, which was slightly raised by the explosion and severely jarred.	1	1	0.4	0.181	......	......	Lead defective.
		1	2	0.4	0.259	123.80	24,820	
		1	3	0.4	0.229	100.67	21,626	
		1	4	0.4	0.229	100.67	21,626	
		1	5	0.4	0.212	88.42	19,832	
		1	6	0.4	0.212	88.42	19,832	
301	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 5 pounds; submergence, 20 feet; depth of water, 120 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Suspended from wooden target, which received a severe shock, throwing irons up weighing 10 pounds.	1	1	0.4	0.200	80.46	18,625	
		1	2	0.4	0.237	106.60	22,465	
		1	3	0.4	0.238	107.30	22,570	
		1	4	0.4	0.210	87.00	19,620	
		1	5	0.4	0.202	81.81	18,833	
		1	6	0.4	0.207	85.10	19,335	
302 to 314.	Fired under wooden target, without the ring. See Appendix C.							

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
315	Explosive, rendrock, 20 per cent. nitro-glycerine; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 101 feet; case, fuze can; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Slight boiling of water.	1	1	0.4	0.046	10.76	4,864	
		1	2	0.4	0.065	16.73	6,537	
		1	3	0.4	0.071	18.75	7,053	
		1	4	0.4	0.056	13.83	5,757	
		1	5	0.4	0.216	.....	......	Lead dented.
		1	6	0.4	0.064	16.42	6,453	
		3	7	0.3	0.032	0.24	389	
		3	8	0.3	0.065	0.62	727	
316	Explosive, rendrock, 40 per cent. nitro-glycerine; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 101 feet; case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Crack appeared in lowering ring.	1	1	0.4	0.134	44.67	12,578	
		1	2	0.4	.....	.....	......	Spoiled.
		1	3	0.4	0.074	19.75	7,300	
		1	4	0.4	0.076	20.46	7,473	
		1	5	0.4	0.064	16.42	6,453	
		1	6	0.4	0.068	17.74	6,797	
		3	7	0.3	0.029	0.21	355	
		3	8	0.3	0.048	0.42	556	
317	Explosive, rendrock, 60 per cent. nitro-glycerine; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 101 feet: case, fuze can, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Socket of No. 2 gauge broke (from old injury).	1	1	0.4	0.114	35.38	10,768	
		1	2	0.4	0.125	40.42	11,770	
		1	3	0.4	0.074	19.75	7,300	
		1	4	0.4	0.080	21.96	7,836	
		1	5	0.4	0.063	16.10	6,370	
		1	6	0.4	0.064	16.42	6,453	
		3	7	0.3	0.039	0.33	475	
		3	8	0.3	0.063	0.60	714	
318	Explosive, rendrock, 20 per cent. nitro-glycerine; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 101 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: A dome of water 1 foot high rose a few seconds after explosion.	1	1	0.4	0.186	72.08	17,309	
		1	2	0.4	0.150	52.64	14,040	
		1	3	0.4	.....	.....	......	Lost lead.
		1	4	0.4	0.101	29.98	9,640	
		1	5	0.4	0.064	16.42	6,453	
		1	6	0.4	0.076	20.46	7,473	
		3	7	0.3	0.063	0.60	714	
		3	8	0.3	0.064	0.61	721	
319	Explosive, rendrock, 40 per cent. nitro-glycerine; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 101 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Ring broke near No. 2 socket, showing a small flaw in iron; no jet, only a boiling of the water.	1	1	0.4	0.124	39.95	11,677	
		1	2	0.4	0.097	28.28	9,276	
		1	3	0.4	0.097	28.28	9,276	
		1	4	0.4	0.077	20.83	7,564	
		1	5	0.4	0.066	17.07	6,624	
		1	6	0.4	0.075	20.08	7,382	
		3	7	0.3	0.082	0.85	898	
		3	8	0.3	0.078	0.79	856	
320	Explosive, rendrock, 40 per cent. nitro-glycerine; ring, 5 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal.	1	1	0.4	0.113	34.94	10,679	
		1	2	0.4	0.064	16.42	6,453	
		1	3	0.4	0.052	12.62	5,395	
		1	4	0.4	0.040	9.10	4,356	
		1	5	0.4	0.081	22.31	7,918	
		1	6	0.4	0.061	15.47	6,203	
		3	7	0.3	0.039	0.33	473	
		3	8	0.3	0.019	0.11	234	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
321	Explosive, rendrock, 60 per cent. nitro-glycerine; ring, 5 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal.	1	1	0.4	0.071	18.75	7,053	
		1	2	0.4	0.094	27.07	9,009	
		1	3	0.4	0.065	16.73	6,537	
		1	4	0.4	0.063	16.10	6,370	
		1	5	0.4	0.070	18.42	6,971	
		1	6	0.4	0.063	16.10	6,370	
		3	7	0.3	0.049	0.43	567	
		3	8	0.3	0.090	0.98	986	
322	Explosive, rendrock, 20 per cent. nitro-glycerine; ring, 5 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Small boil.	1	1	0.4	0.103	30.85	9,816	
		1	2	0.4	0.158	56.80	14,766	
		1	3	0.4	0.069	18.08	6,884	
		1	4	0.4	0.050	12.03	5,215	
		1	5	0.4	0.073	19.42	7,218	
		1	6	0.4	0.074	19.75	7,300	
		3	7	0.3	0.054	0.49	620	
		3	8	0.3	0.097	1.07	1,044	
323	Explosive, rendrock, 40 per cent. nitro-glycerine; ring, 5 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 112 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Small boil.	1	1	0.4	0.166	60.96	15,479	
		1	2	0.4	0.168	62.03	15,658	
		1	3	0.4	0.083	23.00	8,080	
		1	4	0.4	0.084	23.34	8,162	
		1	5	0.4	0.087	24.44	8,416	
		1	6	0.4	0.085	23.69	8,244	
		3	7	0.3	0.072	0.72	803	
		3	8	0.3	0.076	0.76	835	
324	Explosive, rendrock, 60 per cent. nitro-glycerine; ring, 5 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 1, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Small boil.	1	1	0.4	0.124	39.95	11,677	
		1	2	0.4	0.117	36.71	11,036	
		1	3	0.4	0.114	35.38	10,768	
		1	4	0.4	0.124	39.95	11,677	
		1	5	0.4	0.090	25.57	8,674	
		1	6	0.4	0.099	29.13	9,460	
		3	7	0.3	0.089	0.96	975	
		3	8	0.3	0.108	1.24	1,152	
325	Explosive, rendrock, 20 per cent. nitro-glycerine; ring, 5 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Small.	1	1	0.4	0.092	26.32	8,841	
		1	2	0.4	0.099	29.13	9,460	
		1	3	0.4	0.087	24.44	8,416	
		1	4	0.4	0.085	23.69	8,244	
		1	5	0.4	0.086	24.07	8,330	
		1	6	0.4	0.073	19.42	7,218	
		3	7	0.3	0.079	0.81	866	
		3	8	0.3	0.085	0.90	932	
326	Explosive, rendrock, 40 per cent. nitro-glycerine; ring, 5 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal.	1	1	0.4	0.125	40.42	11,770	
		1	2	0.4	0.142	48.56	13,303	
		1	3	0.4	0.117	36.71	11,036	
		1	4	0.4	0.098	28.71	9,368	
		1	5	0.4	0.108	32.82	10,244	
		1	6	0.4	0.096	27.86	9,184	
		3	7	0.3	0.111	1.28	1,181	
		3	8	0.3	0.094	1.03	1,018	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
327	Explosive, rendrock, 60 per cent. nitro-glycerine; ring, 5 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal.	1	1	0.4	0.123	39.47	11,584	
		1	2	0.4	0.144	49.60	13,492	
		1	3	0.4	0.118	34.94	10,697	
		1	4	0.4	0.066	......	......	Pin upset.
		1	5	0.4	0.121	38.52	11,398	
		1	6	0.4	0.112	34.50	10,590	
		3	7	0.3	0.115	1.34	1,217	
		3	8	0.3	0.103	1.16	1,102	
328	Explosive, rendrock, 20 per cent. nitro-glycerine; ring, 5 feet; charge, 5 pounds; submergence, 35 feet; depth of water, 112 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Normal.	1	1	0.4	0.131	43.09	12,282	
		1	2	0.4	0.117	36.71	11,036	
		1	3	0.4	0.097	28.28	9,276	
		1	4	0.4	0.104	31.29	9,904	
		1	5	0.4	0.089	25.19	8,588	
		1	6	0.4	0.098	28.71	9,368	
		3	7	0.3	0.105	1.19	1,122	
		3	8	0.3	0.114	1.33	1,208	
329	Explosive, rendrock, 40 per cent. nitro-glycerine; ring, 5 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 112 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Ring showed warp at top.	1	1	0.4	0.164	59.92	15,303	
		1	2	0.4	0.164	59.92	15,303	
		1	3	0.4	0.164	59.92	15,303	
		1	4	0.4	0.164	59.92	15,303	
		1	5	0.4	0.164	59.92	15,303	
		1	6	0.4	0.164	59.92	15,303	
		3	7	0.3	0.124	1.49	1,306	
		3	8	0.3	0.126	1.53	1,326	
330	Explosive, rendrock, 60 per cent. nitro-glycerine; ring, 5 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 112 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: More warping of ring.	1	1	0.4	0.152	53.64	14,216	
		1	2	0.4	0.142	48.56	13,303	
		1	3	0.4	0.149	51.34	13,949	
		1	4	0.4	0.135	45.20	12,677	
		1	5	0.4	0.095	......	......	Pin upset.
		1	6	0.4	0.143	49.08	13,397	
		3	7	0.3	0.127	1.55	1,336	
		3	8	0.3	0.122	1.46	1,287	
331	Explosive, dynamite No. 1; ring, 3 foot; charge, 100 pounds; submergence, 12 feet; depth of water, 20½ feet; case, buoyant torpedo, model of 1872; ignition, 1 platinum fuze, 40 cells Leclanché battery. Effects: Ring was held by an anchor at 70 feet horizontally from torpedo; water fell on the buoy, but did no damage.	1	1	0.3	0.012	1.18	1,117	
		1	2	0.3	0.008	0.72	803	
		1	3	0.3	0.008	0.72	803	
		1	4	0.3	0.014	1.42	1,263	
		1	5	0.3	0.020	2.30	1,742	
		1	6	0.3	0.012	1.18	1,117	
		3	7	0.3	0.099	1.10	1,062	
332	Explosive, dynamite No. 1; ring, 3 foot; charge, 200 pounds; submergence, 21 feet; depth of water, 21 feet; case, ground torpedo, model 1873; ignition, 40 cells Leclanché battery, 1 platinum fuze. Effects: Ring held by an anchor 80 feet horizontally from torpedo; the explosion killed 3 porpoises at a greater distance.	1	1	0.3	0.010	0.94	959	
		1	2	0.3	0.015	1.54	1,332	
		1	3	0.3	0.007	0.61	719	
		1	4	0.3	0.029	3.60	2,346	
		1	5	0.3	0.016	1.69	1,418	
		1	6	0.3	0.016	1.69	1,418	
		3	7	0.3	0.189	2.82	1,998	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
333	Explosive, rendrock, 40 per cent. nitro-glycerine; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 82 feet; case, fuze can; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Buoy rose 2 feet, followed by small boil in 14 seconds.	1	1	0.4	0.149	.....	......	Hammered.
		1	2	0.4	0.113	.....	......	Do.
		1	3	0.4	0.082	22.65	7,999	
		1	4	0.4	0.085	23.69	8,244	
		1	5	0.4	0.069	18.08	6,884	
		1	6	0.4	0.071	18.75	7,053	
		3	7	0.3	0.041	0.35	494	
		3	8	0.3	0.045	0.38	524	
334	Explosive, dynamite No. 2, loose; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 82 feet; case, fuze can; ignition, Smith's battery, 1 Browne No. 4 fuze. Effects: Boiling appeared 14 seconds after explosion.	1	1	0.4	0.121	.....	......	Hammered.
		1	2	0.4	0.069	18.08	6,884	
		1	3	0.4	0.073	19.42	7,218	
		1	4	0.4	0.074	19.75	7,300	
		1	5	0.4	0.082	22.65	7,999	
		1	6	0.4	0.056	13.83	5,757	
		3	7	0.3	0.029	0.21	355	
		3	8	0.3	0.045	0.38	524	
335	Explosive, dynamite No. 2; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 82 feet; case, can No. 1, sawdust tamping; ignition, Farmer dynamo, 1 platinum fuze. Effects: Normal.	1	1	0.4	0.196	.....	......	Hammered.
		1	2	0.4	0.096	27.86	9,184	
		1	3	0.4	0.150	52.64	14,040	
		1	4	0.4	0.096	27.86	9,184	
		1	5	0.4	0.125	40.42	11,770	
		1	6	0.4	0.115	35.82	10,857	
		3	7	0.3	0.070	0.70	788	
		3	8	0.3	0.085	0.90	932	
336	Explosive, rendrock, 40 per cent. nitro-glycerine; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 82 feet; case, can No. 1, sawdust tamping; ignition, Farmer dynamo, 1 platinum fuze. Effects: Boil rose in 5 seconds.	1	1	0.4	0.198	79.16	18,423	
		1	2	0.4	0.191	74.88	17,756	
		1	3	0.4	0.133	44.14	12,479	
		1	4	0.4	0.113	34.94	10,679	
		1	5	0.4	0.091	25.94	8,758	
		1	6	0.4	0.091	25.94	8,758	
		3	7	0.3	0.049	0.43	567	
		3	8	0.3	.....	.....	......	Tipped over.
337	Explosive, dynamite No. 2; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 82 feet; case, can No. 1, sawdust tamping; ignition, Farmer dynamo, 1 platinum fuze. Effects: Buoy shot up its length. and sunk back to meet a yellow boil.	1	1	0.4	0.143	49.08	13,397	
		1	2	0.4	0.161	58.41	15,044	
		1	2	0.4	0.137	46.13	12,851	
		1	4	0.4	0.145	50.12	13,587	
		1	5	0.4	0.128	41.70	12,018	
		1	6	0.4	0.142	48.56	13,303	
		3	7	0.3	0.083	0.87	910	
		3	8	0.3	0.125	1.51	1,316	
338	Explosive, rendrock, 40 per cent. nitro-glycerine; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 82 feet; case, can No. 1, sawdust tamping; ignition, Farmer dynamo, 1 platinum fuze. Effects: Small boil rose in a few seconds.	1	1	0.4	0.145	50.12	13,587	
		1	2	0.4	0.147	50.73	13,768	
		1	3	0.4	0.172	64.18	16,018	
		1	4	0.4	0.147	50 73	13,768	
		1	5	0.4	0.154	54 65	14,392	
		1	6	0.4	0.115	35.82	10,857	
		3	7	0.3	0.076	0.76	835	
		3	8	0.3	0.110	1.27	1,172	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
339	Explosive, dynamite No. 2; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 platinum fuze. Effects: Normal.	1	1	0.4	0.167	61.50	15,569	
		1	2	0.4	0.162	58.91	15,130	
		1	3	9.4	0.164	59.92	15,303	
		1	4	0.4	0.149	51.34	13,949	
		1	5	0.4	0.135	45.20	12,677	
		1	6	0.4	0.132	43.62	12,381	
		3	7	0.3	0.086	0.92	943	
		3	8	0.3	0.094	1.03	1,018	
340	Explosive, rendrock, 40 per cent. nitro-glycerine; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping: ignition, Farmer dynamo, 1 platinum fuze. Effects: Buoy rose 3 feet; small dome in 3 seconds.	1	1	0.4	0.172	64.18	16,018	
		1	2	0.4	0.165	60.43	15,390	
		1	3	0.4	0.176	66.37	16,383	
		1	4	0.4	0.149	51.34	13,949	
		1	5	0.4	0.156	55.70	14,575	
		1	6	0.4	0.161	58.41	15,044	
		3	7	0.3	0.104	1.17	1,112	
		3	8	0.3	0.135	1.69	1,418	
341	Explosive, dynamite No. 2; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 platinum fuze. Effects: Normal.	1	1	0.4	0.130	42.56	12,183	
		1	2	0.4	0.189	73.74	17,576	
		1	3	0.4	0.228	99.94	21,522	
		1	4	0.4	0.195	77.22	18,122	
		1	5	0.4	0.149	....	......	Pin swedged.
		1	6	0.4	0.201	81.13	18,729	
		3	7	0.3	0.113	1.81	1,199	
		3	8	0.3	0.149	1.96	1,564	
342	Explosive, rendrock, 40 per cent. nitro-glycerine; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 platinum fuze. Effects: Normal.	1	1	0.4	0.168	62.03	15,658	
		1	2	0.4	0.209	86.37	19,525	
		1	3	0.4	6.196	77.87	18,221	
		1	4	0.4	0.191	74.88	17,756	
		1	5	0.4	0.168	62.03	15,658	
		1	6	0.4	0.161	58.41	15,044	
343 to 349	Fired in Crate.—See Appendix B.	3	7	0.3	0.095	1.04	1,026	
		3	8	0.3	0.129	1.58	1,357	
350	Explosive, dynamite No. 2; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 92 feet; case, fuze can; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Usual small boil.	1	1	0.4	0.142	.....	......	Hammered.
		1	2	0.4	0.075	20.08	7,382	
		1	3	0.4	0.043	9.91	4,608	
		1	4	0.4	0.066	17.07	6,624	
		1	5	0.4	0.048	11.39	5,039	
		1	6	0.4	0.057	14.16	5,847	
		3	7	0.3	0.022	0.14	273	
		3	8	0.3	0.066	0.64	739	
351	Explosive, dynamite No. 2; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 92 feet; case, can No. 2, loose; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Small dome.	1	1	0.4	0.175	65.80	16,290	
		1	2	0.4	0.199	79.81	18,524	
		1	3	0.4	0.149	51.34	13,949	
		1	4	0.4	0.146	50.42	13,678	
		1	5	0.4	0.140	47.52	13,113	
		1	6	0.4	0.139	47.06	13,026	
		3	7	0.3	0.102	1.14	1,091	
		3	8	0.3	0.133	1.65	1,398	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
352	Explosive, mica powder No. 2; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 92 feet; case, fuze can, full; ignition, Farmer dynamo, 1 service low tension fuze. Effects: A few bubbles rose several seconds after sound.	1	1	0. 4	0. 041	9. 37	4, 440	
		1	2	0. 4	0. 036	7. 96	3, 988	
		1	3	0. 4	0. 037	8. 24	4, 080	
		1	4	0. 4	0. 037	8. 24	4, 080	
		1	5	0. 4	0. 037	8. 24	4, 080	
		1	6	0. 4	0. 020	3. 87	2, 463	
		3	7	0. 3	0. 013	0. 08	182	
		3	8	0. 3	0. 031	0. 23	377	
353	Explosive, mica powder No. 2; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 92 feet; case, can No. 1, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0. 4	0. 174	65. 26	16, 199	
		1	2	0. 4	0. 082	22. 65	7, 999	
		1	3	0. 4	0. 056	13. 83	5, 757	
		1	4	0. 4	0, 063	16. 10	6, 370	
		1	5	0. 4	0. 056	13. 83	5, 757	
		1	6	0. 4	0. 052	12. 62	5, 395	
		3	7	0. 3	0. 028	0. 20	346	
		3	8	0. 3	0. 041	0. 35	494	
354	Explosive, mica powder No. 2; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 92 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Loud sounds; large yellow boil.	1	1	0. 4	0. 164	59. 92	15, 303	
		1	2	0. 4	0. 115	35. 82	10, 857	
		1	3	0. 4	0. 098	28. 71	9, 368	
		1	4	0. 4	0. 094	27. 07	9, 009	
		1	5	0. 4	0. 090	25. 57	8, 674	
		1	6	0. 4	0. 075	20. 08	7, 382	
		3	7	0. 3	0. 058	0. 55	669	
		3	8	0. 3	0. 057	0. 53	656	
355	Explosive, mica powder No. 2; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 92 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0. 4	0. 179	68. 10	16, 664	
		1	2	0. 4	0. 182	69. 81	16, 942	
		1	3	0. 4	0. 127	41. 28	11, 935	
		1	4	0. 4	0. 132	43. 62	12, 381	
		1	5	0. 4	0. 112	34. 50	10, 590	
		1	6	0. 4	0. 105	31. 62	9, 992	
		3	7	0. 3	0. 083	0. 87	910	
		3	8	0. 3	0. 092	1. 00	1, 002	
356	Explosive, mica powder No. 2; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 92 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Less than preceding shot.	1	1	0. 4	0. 147	50. 73	13, 768	
		1	2	0. 4	0. 125	40. 42	11, 770	
		1	3	0. 4	0. 105	31. 62	9, 992	
		1	4	0. 4	0. 119	37. 60	11, 215	
		1	5	0. 4	0. 098	28. 71	9, 368	
		1	6	0. 4	0. 117	36. 71	11, 036	
		3	7	0. 3	0. 092	1. 00	1, 002	
		3	8	0. 3	0. 092	1. 00	1. 002	
357	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 92 feet; case, fuze can; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0. 4	0. 146	50. 42	13, 678	
		1	2	0. 4	0. 097	28. 28	9, 276	
		1	3	0. 4	0. 070	18. 42	6, 971	
		1	4	0. 4	0. 080	21. 96	7, 836	
		1	5	0. 4	0. 066	17. 07	6, 624	
		1	6	0. 4	0. 060	15. 15	6, 119	
		3	7	0. 3	0. 040	0. 34	487	
		3	8	0. 3	0. 026	0. 30	450	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
358	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 92 feet; case, can No. 1, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.213	89.13	19,938	
		1	2	0.4	0.178	67.52	16,570	
		1	3	0.4	0.130	42.56	12,183	
		1	4	0.4	0.150	52.64	14,040	
		1	5	0.4	0.112	34.50	10,590	
		1	6	0.4	0.102	30.42	9,728	
		3	7	0.3	0.076	0.76	835	
		3	8	0.3	0.109	1.25	1,162	
359	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 92 feet; case, can No. 1; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.189	73.74	17,576	
		1	2	0.4	0.159	57.35	14,862	
		1	3	0.4	0.195	77.22	18,120	
		1	4	0.4	0.157	56.25	14,671	
		1	5	0.4	0.139	47.06	13,026	
		1	6	0.4	0.154	54.65	14,392	
		3	7	0 3	0.121	1.45	1,278	
		3	8	0.4	0.076	1.22	1,142	
360	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 92 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 service platinum fuze. Effects: Buoy shot up 5 feet before any surface disturbance of water occurred; as usual.	1	1	0.4	0.213	89.13	19,938	
		1	2	0.4	0.123	......	......	Defaced.
		1	3	0.4	0.194	76.64	18,029	
		1	4	0.4	0.175	65.80	16,290	
		1	5	0.4	0.176	66.37	16,383	
		1	6	0.4	0.163	59.42	15,217	
		3	7	0.3	0.125	1.51	1,316	
		3	8	0.3	0.136	1.71	1,427	
361	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 92 feet; case, can No. 2; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.207	85.10	19,335	
		1	2	0.4	0.194	76.64	18,029	
		1	3	0.4	0.209	86.37	19,525	
		1	4	0.4	0.228	99.94	21,522	
		1	5	0.4	0.202	81.81	18,833	
		1	6	0.4	0.205	83.84	19,145	
		3	7	0.3	0.146	1.89	1,529	
		3	8	0.3	0.158	2.16	1,667	
362	Explosive, mica powder No. 2; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 90 feet; case, fuze can, full; ignition, Farmer dynamo, 1 service low tension fuze. Effects: In 10 seconds a few clear air bubbles rose; buoy hardly moved.	1	1	0.4	0.121	......	......	Loose pin.
		1	2	0.4	0.037	8.24	4,080	
		1	3	0.4	0.052	12.62	5,395	
		1	4	0.4	0.039	8.81	4,264	
		1	5	0.4	0.039	8.81	4,264	
		1	6	0.4	0.030	6.36	3,431	
		3	7	0.3	0.012	0.07	172	
		3	8	0.3	0.014	0.09	191	
363	Explosive, mica powder No. 2; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 90 feet; case, can No. 1, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Clear bubbles rose in 8 seconds.	1	1	0.4	....	......	......	Broke pin.
		1	2	0.4	0.078	21.21	7,654	
		1	3	0.4	0.081	22.31	7,918	
		1	4	0.4	0.069	18.08	6,884	
		1	5	0.4	0.065	16.73	6,537	
		1	6	0.4	0.079	21.58	7,745	
		3	7	0.3	0.024	0.17	304	
		3	8	0.3	0.037	0.30	451	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
364	Explosive, mica powder No. 2; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 60 feet; case, can No. 1; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Boil in 8 seconds.	1	1	0.4	0.177	.....	......	Hammered.
		1	2	0.4	0.138	46.59	12,939	
		1	3	0.4	0.127	41.28	11,935	
		1	4	0.4	0.139	47.06	13,026	
		1	5	0.4	0.109	33.22	10,328	
		1	6	0.4	0.113	34.94	10,679	
		3	7	0.3	0.045	0.38	524	
		3	8	0.3	0.054	0.49	620	
365	Explosive, mica powder No. 2 ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 90 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Boil in 6 seconds.	1	1	0.4	0.168	62.03	15,658	
		1	2	0.4	0.181	69.24	16,850	
		1	3	0.4	0.107	32.42	10,160	
		1	4	0.4	0.142	48.56	13,303	
		1	5	0.4	0.103	30.85	9,816	
		1	6	0.4	0.120	38.05	11,305	
		3	7	0.3	0.051	0.45	588	
		3	8	0.3	0.078	0.79	856	
366	Explosive, mica powder No. 2; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 90 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Boil appeared in 4 seconds; the usual triple sound very distinct.	1	1	0.4	0.149	51.84	13,949	
		1	2	0.4	0.142	48.56	13,303	
		1	3	0.4	0.120	38.05	11,305	
		1	4	0.4	0.129	42.13	12,100	
		1	5	0.4	0.102	30.42	9,728	
		1	6	0.4	0.142	48.56	13,303	
		3	7	0.3	0.089	0.96	975	
		3	8	0.3	0.070	0.70	788	
367	Explosive, mammoth powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 90 feet; case, 24-gallon keg, with diaphragm, air up; ignition, Farmer dynamo, 1 service, low tension fuze. Effects: Dome dark with unburned grains rose to surface.	1	1	0.4	0.004	0.22	369	
		1	2	0.4	0.003	0.17	304	
		1	3	0.4	0.003	0.17	304	
		1	4	0.4	0.002	0.11	232	
		1	5	0.4	0.004	0.22	369	
		1	6	0.4	0.004	0.22	369	
		3	7	0.4	0.001	0.001	10	
		3	8	0.4	0.001	0.001	10	
368	Explosive, cannon powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 90 feet; case, 24-gallon keg, diaphragmed, air up; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Small jet.	1	1	0.4	0.020	1.42	1,262	
		1	2	0.4	0.014	0.94	953	
		1	3	0.4	0.019	1.34	1,211	
		1	4	0.4	0.010	0.64	742	
		1	5	0.4	0.024	1.80	1,475	
		1	6	0.4	0.005	0.28	428	
		3	7	0.4	0.004	0.002	15	
		3	8	0.4	0.009	0.004	26	
369	Explosive, Oliver powder; ring, 4 foot; charge, 72½ pounds; submergence, 35 feet; depth of water, 90 feet; case, 24-gallon keg, diaphragmed, air up; ignition, Farmer dynamo, 1 service low tension fuze. Effects: A brown, unglazed powder; mixture of grades f. f. and f. f. f.; jet dark with unburned powder.	1	1	0.4	0.004	0.22	369	
		1	2	0.4	0.003	0.17	304	
		1	3	0.4	0.003	0.17	304	
		1	4	0.4	0.001	0.06	146	
		1	5	0.4	0.003	0.17	304	
		1	6	0.4	0.002	0.11	232	
		3	7	0.4	0.002	0.001	11	
		3	8	0.4	0.001	0.001	9	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
370	Explosive, mortar powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 90 feet; case, 24-gallon keg, diaphragmed, air up; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	.....	.....	......	Mislaid.
		1	2	0.4	0.098	10.61	4,824	
		1	3	0.4	0.098	10.30	4,731	
		1	4	0.4	0.058	5.84	3,058	
		1	5	0.4	0.081	8.25	4,079	
		1	6	0.4	0.082	8.38	4,121	
		3	7	0.4	0.031	0.018	67	
		3	8	0.4	0.052	0.035	107	
371 to 377	Fired under wooden target.—See Appendix C.							
378	Explosive, mica powder No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 75 feet; case, fuze can, full; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.054	13.21	5,576	
		1	2	0.4	0.087	24.44	8,416	
		1	3	0.4	0.071	18.75	7,053	
		1	4	0.4	0.063	16.10	6,370	
		1	5	0.4	0.055	13.50	5,666	
		1	6	0.4	0.045	10.45	4,776	
		3	7	0.3	0.013	0.08	182	
		3	8	0.3	0.035	0.27	337	
379	Explosive, mica powder No. 1; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 1, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.223	.....	......	Hammered.
		1	2	0.4	0.139	47.06	13,026	
		1	3	0.4	0.111	34.06	10,501	
		1	4	0.4	0.113	34.94	10,679	
		1	5	0.4	0.099	29.13	9,460	
		1	6	0.4	0.095	27.44	9,092	
		3	7	0.3	0.064	0.61	721	
		3	8	0.3	0.054	0.49	620	
380	Explosive, mica powder No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 1; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Socket of gauge No. 2 broken by gradual warping of ring.	1	1	0.4	0.248	.....	......	Hammered.
		1	2	0.4	0.137	46.13	12,851	
		1	3	0.4	0.151	53.14	14,128	
		1	4	0.4	0.150	52.64	14,040	
		1	5	0.4	0.119	37.60	11,215	
		1	6	0.4	0.138	46.59	12,939	
		3	7	0.3	0.075	0.75	825	
		3	8	0.3	0.090	0.98	986	
381	Explosive, mica powder No. 2; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Less than usual for a 4-pound charge.	1	1	0.4	0.172	64.18	16,018	
		1	2	0.4	0.151	53.14	14,128	
		1	3	0.4	0.131	43.09	12,282	
		1	4	0.4	0.146	50.42	13,678	
		1	5	0.4	0.131	43.09	12,282	
		1	6	0.4	0.133	44.14	12,479	
		3	7	0.3	0.061	0.59	701	
		3	8	0.3	0.089	0.96	975	
382	Explosive, mica powder No. 2; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Yellow dome; buoy rising 3 feet.	1	1	0.4	0.150	52.64	14,040	
		1	2	0.4	0.143	49.08	13,397	
		1	3	0.4	0.132	43.62	12,381	
		1	4	0.4	0.144	49.60	13,492	
		1	5	0.4	0.125	40.42	11,770	
		1	6	0.4	0.120	38.05	11,305	
		3	7	0.3	0.099	1.10	1,062	
		3	8	0.3	0.082	0.85	898	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
383	Explosive, mica powder No. 2; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Like the last.	1	1	0.4	0.144	49.60	13,492	
		1	2	0.4	0.139	47.06	13,026	
		1	3	0.4	0.123	39.47	11,584	
		1	4	0.4	0.134	44.67	12,578	
		1	5	0.4	0.129	42.13	12,100	
		1	6	0.4	0.121	38.52	11,398	
		3	7	0.3	0.097	1.07	1,044	
		3	8	0.3	0.089	0.96	975	
384	Explosive, mica powder No. 1; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.208	85.74	19,430	
		1	2	0.4	0.199	79.81	18,524	
		1	3	0.4	0.145	50.12	13,587	
		1	4	0.4	0.177	66.95	16,477	
		1	5	0.4	0.152	53.64	14,216	
		1	6	0.4	0.138	46.59	12,939	
		3	7	0.3	0.095	1.04	1,026	
		3	8	0.3	0.099	1.10	1,062	
385	Explosive, mica powder No. 1; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.181	69.24	16,850	
		1	2	0.4	0.162	58.91	15,130	
		1	3	0.4	0.149	51.34	13,949	
		1	4	0.4	0.174	65.26	16,199	
		1	5	0.4	0.148	51.03	13,859	
		1	6	0.4	0.134	44.67	12,578	
		3	7	0.3	0.073	0.73	810	
		3	8	0.3	0.064	0.61	721	
386	Explosive, mica powder No. 1; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.218	92.74	20,474	
		1	2	0.4	0.152	53.64	14,216	
		1	3	0.4	0.193	76.05	17,938	
		1	4	0.4	0.205	83.84	19,145	
		1	5	0.4	0.185	71.52	17,220	
		1	6	0.4	0.190	74.30	17,665	
		3	7	0.3	0.091	0.99	994	
		3	8	0.3	0.116	1.36	1,227	
387	Explosive, musket powder; ring, 4 foot; charge, 100 pounds; submergence, 35 feet; depth of water, 75 feet; case, 24-gallon keg, diaphragmed, air up; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Fine jet. Last shot of season (October 28, 1874).	1	1	0.4	0.075	7.42	3,802	
		1	2	0.4	0.063	5.96	3,283	
		1	3	0.4	0.126	15.11	6,106	
		1	4	0.4	0.058	5.34	3,058	
		1	5	0.4	0.101	11.06	4,961	
		1	6	0.4	0.099	10.76	4,871	
		3	7	0.3	0.046	0.016	61	
		3	8	0.3	0.144	0.071	172	
388 to 399	Fired near iron target or in crate.—See Appendices B and C.							
400	Explosive, granulated gun-cotton, wet; ring, 4 foot; charge, 1.6 pounds; submergence, 35 feet; depth of water, 53 feet; case, can No. 1, full; ignition, Smith's battery, 1 Abel fuze, and ¼ ounce dry gun-cotton; total weight, including water, 2 pounds; 1 fuze failed to explode. Effects: Small boil. First shot of season (August 4, 1876).	1	1	0.4	0.150	52.64	14,040	
		1	2	0.4	0.130	42.56	12,183	
		1	3	0.4	0.120	38.05	11,305	
		1	4	0.4	0.094	27.07	9,009	
		1	5	0.4	0.083	23.00	8,080	
		1	6	0.4	0.080	21.96	7,836	
		3	7	0.3	0.056	0.52	643	
		3	8	0.3	0.081	0.84	887	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
401	Explosive, granulated gun-cotton, wet; ring, 4 foot; charge, 2.4 pounds; submergence, 35 feet; depth of water, 53 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Abel fuse, and ¾ ounce dry gun-cotton; weight of charge, including water, 3 pounds. Effects: Normal.	1	1	0.4	0.153	54.15	14,304	
		1	2	0.4	0.140	47.52	13,113	
		1	3	0.4	0.113	34.94	10,679	
		1	4	0.4	0.122	39.00	11,491	
		1	5	0.4	0.092	26.32	8,841	
		1	6	0.4	0.098	28.71	9,368	
		3	7	0.3	0.110	1.27	1,172	
		3	8	0.3	0.070	0.70	788	
402	Explosive, granulated gun-cotton, wet; ring, 4 foot; charge, 2.4 pounds; submergence, 35 feet; depth of water, 53 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Abel fuse, and ¾ ounce dry gun-cotton; charge, including water, weighs 3 pounds. Effects: Small boil.	1	1	0.4	0.133	43.62	12,381	
		1	2	0.4	0.100	29.55	9,552	
		1	3	0.4	0.097	28.28	9,276	Broke pin.
		1	4	0.4	0.100	29.55	9,552	
		1	5	0.4	0.076	20.46	7,473	
		1	6	0.4	0.070	18.42	6,971	
		3	7	0.3	0.075	0.75	825	
		3	8	0.3	0.068	0.67	764	
403	Explosive, granulated gun-cotton, wet; ring, 4 foot; charge, 2.4 pounds; submergence, 35 feet; depth of water, 53 feet; case, rubber bag; ignition, Smith's battery, 1 Abel fuse, and ¾ ounce dry gun-cotton; total charge, including water, weighs 3 pounds. Effects: Fuse failed to explode on first trial; second one went.	1	1	0.4	0.142	48.56	13,308	
		1	2	0.4	0.143	49.08	13,397	
		1	3	0.4	0.136	45.66	12,764	
		1	4	0.4	0.162	58.91	15,130	
		1	5	0.4	0.058	14.49	5,938	
		1	6	0.4	.....	......	......	Tipped over.
		3	7	0.3	0.099	1.10	1,062	
		3	8	0.3	0.066	0.64	739	
404	Explosive, granulated gun-cotton, wet; ring, 4 foot; charge, 3.2 pounds; submergence, 35 feet; depth of water, 53 feet; case, can No. 2, sawdust tamping; ignition, Smith's battery, 1 Abel fuse, and ¾ ounce dry gun-cotton; total charge weighs 4 pounds, including water. Effects: Three fuses failed in succession; tested again in laboratory they all failed with an inch spark, but exploded with 40-cell battery or Farmer dynamo.	1	1	0.4	0.144	49.60	13,492	
		1	2	0.4	0.163	59.42	15,217	
		1	3	0.4	0.136	45.66	12,764	
		1	4	0.4	0.136	45.66	12,764	
		1	5	0.4	0.127	41.28	11,935	
		1	6	0.4	0.120	38.05	11,305	
405	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 65 feet; case, can No. 1; ignition, Farmer dynamo and 1 service low tension fuse; charge received from California 5 years before. Effects: Normal.	1	1	0.4	0.172	64.18	16,018	
		1	2	0.4	0.247	114.20	23,531	
		1	3	0.4	0.181	69.24	16,850	
		1	4	0.4	0.181	69.24	16,850	
		1	5	0.4	0.164	59.92	15,303	
		1	6	0.4	0.171	63.64	15,928	
		3	7	0.3	0.122	1.46	1,287	
		3	8	0.3	0.093	1.02	1,010	
406	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 65 feet; case, can No. 1; ignition, Farmer dynamo, 1 service low tension fuze; charge received from California 5 years before. Effects: Normal.	1	1	0.4	0.169	62.57	15,748	
		1	2	0.4	0.190	74.30	17,665	
		1	3	0.4	0.187	72.63	17,398	
		1	4	0.4	0.160	57.90	14,957	
		1	5	0.4	0.156	55.70	14,575	
		1	6	0.4	0.169	62.57	15,748	
		3	7	0.3	0.167	2.34	1,760	
		3	8	0.3	0.114	1.33	1,208	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
407	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 65 feet; case, can No. 1 full; ignition, Farmer dynamo, 1 service low tension fuze; charge received from New Jersey three years before. Effects: Normal; broke cap of No. 4 gauge.	1	1	0.4	0.209	86.37	19,525	
		1	2	0.4	0.264	128.00	25,382	
		1	3	0.4	0.172	64.18	16,018	
		1	4	0.4	0.166	60.96	15,479	
		1	5	0.4	0.151	53.14	14,128	
		1	6	0.4	0.152	53.64	14,216	
		3	7	0.3	0.133	1.65	1,398	
		3	8	0.3	0.091	0.99	994	
408	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 65 feet; case, can No. 1, full; ignition, Farmer dynamo, 1 service low tension fuze; charge received from New Jersey three years before. Effects: Broke socket of wire rope.	1	1	0.4	0.179	68.10	16,664	
		1	2	0.4	0.210	87.00	19,620	
		1	3	0.4	0.163	59.42	15,217	
		1	4	0.4	0.161	58.41	15,044	
		1	5	0.4	0.166	60.96	15,479	
		1	6	0.4	0.157	56.25	14,671	
		3	7	0.3	0.121	1.45	1,278	
		3	8	0.3	0.098	1.08	1,053	
409	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 65 feet; case, can No. 1, full; ignition, Farmer dynamo, 1 service low tension fuze; charge just received from New Jersey. Effects: Broke cap of No. 3 gauge.	1	1	0.4	0.176	66.37	16,383	
		1	2	0.4	0.184	70.95	17,127	
		1	3	0.4	0.185	71.52	17,220	
		1	4	0.4	0.191	74.88	17,756	
		1	5	0.4	0.171	63.64	15,928	
		1	6	0.4	0.159	57.35	14,862	
		3	7	0.3	0.106	1.21	1,132	
		3	8	0.3	0.101	1.13	1,081	
410	Explosive, dynamite No. 1, loose; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 65 feet; case, can No. 1, full; ignition, Farmer dynamo, 1 service low tension fuze; charge just received from New Jersey. Effects: Normal.	1	1	0.4	0.179	68.10	16,664	
		1	2	0.4	0.179	68.10	16,664	
		1	3	0.4	0.162	58.91	15,130	
		1	4	0.4	0.179	68.10	16,664	
		1	5	0.4	0.145	50.12	13,587	
		1	6	0.4	0.146	50.42	13,678	
		3	7	0.3	0.109	1.25	1,162	
		3	8	0.3	0.117	1.38	1,237	
411	Explosive, granulated gun-cotton, wet; ring, 4 foot; charge, 2.4 pounds; submergence, 35 feet; depth of water, 65 feet; case, rubber bag; ignition, Farmer dynamo, 1 Abel fuze, and ½ ounce dry gun-cotton; total charge weighs 3 pounds, including water. Effects: Normal.	1	1	0.4	0.188	46.59	12,939	
		1	2	0.4	0.176	66.37	16,383	
		1	3	0.4	0.144	49.60	13,492	
		1	4	0.4	0.137	46.13	12,651	
		1	5	0.4	0.124	39.95	11,677	
		1	6	0.4	0.129	42.13	12,100	
		3	7	0.3	0.097	1.07	1,044	
		3	8	0.3	0.093	1.02	1,010	
412	Explosive, granulated gun-cotton, wet; ring, 4 foot; charge, 1.6 pounds; submergence, 35 feet; depth of water, 65 feet; case, can No. 1, full; ignition, Farmer dynamo, 1 Abel fuze, and ½ ounce of dry gun-cotton; charge, including water, weighs 2 pounds. Effects: Normal.	1	1	0.4	0.161	58.41	15,044	
		1	2	0.4	0.184	.....	......	Two pin marks.
		1	3	0.4	0.127	41.28	11,985	
		1	4	0.4	0.116	36.27	10,947	
		1	5	0.4	0.093	26.69	8,925	
		1	6	0.4	0.097	28.28	9,276	
		3	7	0.3	0.078	0.79	856	
		3	8	0.3	0.063	0.60	714	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
413	Explosive, granulated gun-cotton, wet; ring, 4 foot; charge, 3.2 pounds; submergence, 35 feet; depth of water, 65 feet; case, can No. 2, sawdust tamping; ignition, Farmer dynamo, 1 Abel fuze, and ¾ ounce dry gun-cotton; charge weighs, including water, 4 pounds. Effects: Normal.	1	1	0.4	0.132	43.62	12,381	
		1	2	0.4	0.147	50.73	13,678	
		1	3	0.4	0.143	49.08	13,397	
		1	4	0.4	0.170	63.10	15,837	
		1	5	0.4	0.123	39.47	11,584	
		1	6	0.4	0.113	34.94	10,679	
		3	7	0.3	0.101	1.13	1,081	
		3	8	0.3	0.083	0.87	910	
414	Explosive, granulated gun-cotton, wet; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 65 feet; case, can No. 2, full; ignition, Farmer dynamo, 1 Abel fuze, and ¾ ounce dry gun-cotton; charge, including water, weighs 5 pounds. Effects: Normal. Fired duplicate shot. The wet gun-cotton failed to be exploded by the dry primer, and was recovered in the can torn open by the latter.	1	1	0.4	0.153	54.15	14,303	
		1	2	0.4	0.191	74.88	17,756	
		1	3	0.4	0.166	60.96	15,479	
		1	4	0.4	0.166	60.96	15,479	
		1	5	0.4	0.088	24.87	8,502	
		1	6	0.4	0.074	19.75	7,300	
		3	7	0.3	0.119	1.41	1,258	
		3	8	0.3	0.101	1.13	1,081	
415	Explosive, disc gun-cotton, wet; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 62 feet; case, can No. 1, full; ignition, Farmer dynamo, 1 Abel fuze, and 1¾ ounces dry gun-cotton; this gun-cotton was charged with 27 per cent. of fresh water, and the can was tight. Effects: The explosion was only partial.	1	1	0.4	0.015	2.74	1,957	
		1	2	0.4	0.020	3.87	2,463	
		1	3	0.4	0.013	2.34	1,762	
		1	4	0.4	0.024	4.84	2,855	
		1	5	0.4	0.014	2.54	1,860	
		1	6	0.4	0.013	2.34	1,762	
		3	7	0.3	0.005	0.03	96	
		3	8	0.3	0.002	0.02	52	
416	Explosive, disc gun-cotton, wet; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 62 feet; case, can No. 1, full; ignition, Farmer dynamo, 1 Abel fuze, and 1¾ ounces dry gun-cotton; this gun-cotton was charged with 27 per cent. of fresh water, and the can was tight. Effects: The explosion was only partial.	1	1	0.4	0.015	2.74	1,957	
		1	2	0.4	0.018	3.42	2,261	
		1	3	0.4	0.012	2.13	1,651	
		1	4	0.4	0.012	2.13	1,651	
		1	5	0.4	0.013	2.34	1,762	
		1	6	0.4	0.009	1.54	883	
		3	7	0.3	.....	.....	......	Lost.
		3	8	0.3	0.003	0.02	69	
417	Explosive, gun-cotton, dry; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 62 feet; case, can No. 1, full; ignition, Farmer dynamo, 1 Abel fuze. Effects: Normal.	1	1	0.4	0.124	39.95	11,677	
		1	2	0.4	0.143	49.08	13,397	
		1	3	0.4	0.116	36.27	10,949	
		1	4	0.4	0.128	41.70	12,018	
		1	5	0.4	0.109	33.22	10,328	
		1	6	0.4	0.083	23.00	8,080	
		3	7	0.3	0.078	0.79	856	
		3	8	0.3	0.066	0.64	739	
418	Explosive, gun-cotton, dry; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 62 feet; case, can No. 1, full; ignition, Farmer dynamo, 1 Abel fuze. Effects: Normal.	1	1	0.4	0.123	39.47	11,584	
		1	2	0.4	0.100	29.55	9,552	
		1	3	0.4	0.138	46.59	12,939	
		1	4	0.4	0.146	50.42	13,678	
		1	5	0.4	0.103	30.85	9,816	
		1	6	0.4	0.107	32.42	10,160	
		3	7	0.3	0.078	0.79	856	
		3	8	0.3	0.076	0.76	835	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
419	Explosive, gun-cotton, wet; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 62 feet; case, can No. 2, full; ignition, Farmer dynamo, 1 service low tension fuze, and 1⅜ ounces dry gun-cotton; charge contained 25 per cent. of fresh water. Effects: Buoy shot up 5 feet, and fell over on a large dome of water rising around it.	1	1	0.4	0.189	73.74	17,576	
		1	2	0.4	0.223	96.33	21,002	
		1	3	0.4	0.187	72.63	17,398	
		1	4	0.4	0.205	83.84	19,145	
		1	5	0.4	0.169	62.57	15,748	
		1	6	0.4	0.167	61.50	15,569	
		3	7	0.3	0.175	2.50	1,841	
		3	8	0.3	0.118	1.39	1,248	
420	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 62 feet; case, rubber bag; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.229	100.67	21,626	
		1	2	0.4	0.229	100.67	21,626	
		1	3	0.4	0.210	87.00	19,620	
		1	4	0.4	0.183	70.38	17,035	
		1	5	0.4	0.171	63.64	15,928	
		1	6	0.4	0.136	45.66	12,704	
		3	7	0.3	0.133	1.65	1,398	
		3	8	0.3	0.118	1.39	1,248	
421	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 62 feet; case, rubber bag; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.177	66.95	16,477	
		1	2	0.4	0.199	79.81	18,524	
		1	3	0.4	0.199	79.81	18,524	
		1	4	0.4	0.207	85.10	19,335	
		1	5	0.4	0.160	57.90	14,957	
		1	6	0.4	0.151	53.14	14,128	
		3	7	0.3	0.133	1.65	1,398	
		3	8	0.3	0.116	1.36	1,227	
422	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 62 feet; case, can No. 1, full; ignition, Farmer dynamo, 1 service low tension fuze. Gauge-pins lengthened from 1.5 inches (usual) to 2 inches. Effects: Normal.	1	1	0.4	0.137	46.13	12,851	
		1	2	0.4	0.177	66.95	16,477	
		1	3	0.4	0.150	52.64	14,040	
		1	4	0.4	0.191	74.88	17,756	
		1	5	0.4	0.139	47.06	13,026	
		1	6	0.4	0.145	50.12	13,587	
		3	7	0.3	0.115	1.34	1,217	
		3	8	0.3	0.105	1.19	1,122	
423	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 62 feet; case, can No. 1, full; ignition, Farmer dynamo, 1 service low tension fuze. Gauge-pins lengthened from 1.5 inches (usual) to 2.0 inches. Effects: Normal.	1	1	0.4	0.142	48.56	13,303	
		1	2	0.4	0.202	81.81	18,833	
		1	3	0.4	0.164	59.92	15,303	
		1	4	0.4	0.175	65.80	16,290	
		1	5	0.4	0.139	47.06	13,026	
		1	6	0.4	0.115	35.82	10,857	
		3	7	0.3	0.135	1.69	1,418	
		3	8	0.3	0.106	1.21	1,132	
424	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 62 feet; case, can No. 1, full; ignition, Farmer dynamo, 1 service low tension fuze. Gauge-pins lengthened from 1.5 inches (usual) to 2 inches. Effects: Normal.	1	1	0.4	0.139	47.06	13,026	Badly jammed.
		1	2	0.4	0.186	72.08	17,309	
		1	3	0.4	0.154	54.65	14,392	
		1	4	0.4	0.170	63.10	15,837	
		1	5	0.4	0.149	51.34	13,949	
		1	6	0.4	0.089	25.19	8,588	Badly jammed.
		3	7	0.3	0.113	1.31	1,199	
		3	8	0.3	0.131	1.62	1,377	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
425	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 62 feet; case, can No. 1, full; ignition, Farmer dynamo, 1 service low tension fuze. Gauges 1, 3, 5, usual pins; gauges 2, 4, 6, pins 2 inches long. Effects: Normal.	1	1	0.4	0.198	76.05	17,938	
		1	2	0.4	0.179	68.10	16,664	
		1	3	0.4	0.172	64.18	16,018	
		1	4	0.4	0.149	51.34	13,949	
		1	5	0.4	0.169	62.57	15,748	
		1	6	0.4	0.134	44.67	12,578	
		3	7	0.3	0.127	1.55	1,336	
		3	8	0.3	0.101	1.13	1,061	
426	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 62 feet; case, can No. 1, full; ignition, Farmer dynamo, 1 service low tension fuze. Gauges 1, 3, 5, usual pins (1.5 inches); gauges 2, 4, 6, pins 2 inches long. Effects: Normal.	1	1	0.4	0.196	77.87	18,221	
		1	2	0.4	0.237	106.60	22,465	
		1	3	0.4	0.184	70.95	17,127	
		1	4	0.4	0.169	62.57	15,748	
		1	5	0.4	0.174	65.26	16,199	
		1	6	0.4	0.144	49.60	13,492	
		3	7	0.3	0.106	1.21	1,132	
		3	8	0.3	0.117	1.38	1,237	
427	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 62 feet; case, can No. 1, full; ignition, Farmer dynamo, 1 service low tension fuze. Gauges 1, 3, 5, usual pins (1.5 inches); gauges 2, 4, 6, pins 2 inches long. Effects: Normal.	1	1	0.4	0.165	60.43	15,390	
		1	2	0.4	0.210	87.00	19,620	
		1	3	0.4	0.164	59.92	15,303	
		1	4	0.4	0.182	69.81	16,942	
		1	5	0.4	0.160	57.90	14,957	
		1	6	0.4	0.139	47.06	13,026	
		3	7	0.3	0.125	1.51	1,316	
		3	8	0.3	0.105	1.19	1,122	
428	Fired under iron target.—See Appendix C.							
429	Explosive, vulcan powder No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 75 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. Effects: Buoy rose 1 foot, 3 sounds; large upward boil.	1	1	0.4	0.079	21.58	7,745	
		1	2	0.4	0 091	25.94	8,758	
		1	3	0.4	0.063	16.10	6,370	
		1	4	0.4	0.064	16.42	6,453	
		1	5	0.4	0.049	11.71	5,127	
		1	6	0.4	0.057	14.16	5,847	
		3	7	0.3	0.017	0.10	217	
		3	8	0.3	0.038	0.31	463	
430	Explosive, vulcan powder No. 1; ring, 4 foot, charge, 1 pound; submergence, 35 feet; depth of water, 75 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.114	.....	......	Crushed obliquely.
		1	2	0.4	0.142	.....	......	Do.
		1	3	0.4	0.078	21.21	7,654	
		1	4	0.4	0.073	19.42	7,218	
		1	5	0.4	0.062	15.78	6,286	
		1	6	0.4	0.040	9.10	4,356	
		3	7	0.3	0.023	0.16	289	
		3	8	0.3	0.043	0.36	509	
431	Explosive, vulcan powder No. 1; ring, 4 foot; charge, 2 pounds; submergence, 3 feet; depth of water, 75 feet; case, can No. 1, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Buoy rose 2½ feet.	1	1	0.4	0.116	36.27	10,947	
		1	2	0.4	0.116	36.27	10,947	
		1	3	0.4	0.101	29.98	9,640	
		1	4	0.4	0.103	30.85	9,816	
		1	5	0.4	0.093	26.69	8,925	
		1	6	0.4	0.090	25.57	8,674	
		3	7	0.3	0.058	0.55	669	
		3	8	0.3	0.078	0.79	856	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
432	Explosive, vulcan powder No. 1; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 1, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuse. Effects: Normal.	1	1	0.4	0.102	30.42	9,728	
		1	2	0.4	0.172	......	......	Enlarged pin-hole.
		1	3	0.4	0.109	33.22	10,328	
		1	4	0.4	0.099	29.13	9,460	
		1	5	0.4	0.088	24.82	8,502	
		1	6	0.4	0.084	23.34	8,162	
		3	7	0.3	0.045	0.38	524	
		3	8	0.3	0.078	0.79	856	
433	Explosive, vulcan powder No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 1, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuse. Effects: Buoy rose 3½ feet; dome about 1 foot high.	1	1	0.4	0.131	43.09	12,282	
		1	2	0.4	0.110	33.62	10,412	
		1	3	0.4	0.173	64.72	16,109	
		1	4	0.4	0.142	48.56	13,303	
		1	5	0.4	0.124	39.95	11,677	
		1	6	0.4	0.113	34.94	10,679	
		3	7	0.3	0.132	1.65	1,387	
		3	8	0.3	0.111	1.28	1,181	
434	Explosive, vulcan powder No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 1, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuse. Effects: Normal.	1	1	0.4	0.126	40.85	11,853	
		1	2	0.4	0.172	64.18	16,010	
		1	3	0.4	0.134	44.67	12,578	
		1	4	0.4	0.135	45.20	12,677	
		1	5	0.4	0.106	32.02	10,076	
		1	6	0.4	0.105	31.62	9,992	
		3	7	0.3	0.083	0.87	910	
		3	8	0.3	0.090	0.98	986	
435	Explosive, vulcan powder No. 1; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuse. Effects: Buoy rose 5 feet and fell over in a 1-foot dome of water.	1	1	0.4	0.150	52.64	14,040	
		1	2	0.4	0.171	63.64	15,928	
		1	3	0.4	0.133	44.14	12,479	
		1	4	0.4	0.152	53.64	14,216	
		1	5	0.4	0.126	40.85	11,853	
		1	6	0.4	0.168	62.03	15,658	
		3	7	0.3	0.104	1.17	1,112	
		3	8	0.3	0.093	1.02	1,010	
436	Explosive, vulcan powder No. 1; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuse. Effects: Normal.	1	1	0.4	0.154	54.65	14,392	
		1	2	0.4	0.166	60.96	15,479	
		1	3	0.4	0.145	50.12	13,587	
		1	4	0.4	0.141	48.04	13,208	
		1	5	0.4	0.130	42.56	12,183	
		1	6	0.4	0.147	50.73	13,768	
		3	7	0.3	0.109	1.25	1,162	
		3	8	0.3	0.088	0.95	964	
437	Explosive, vulcan powder No. 1; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuse. Effects: Dome of water 3 feet high.	1	1	0.4	0.231	102.10	21,835	
		1	2	0.4	0.209	86.37	19,525	
		1	3	0.4	0.162	58.91	15,130	
		1	4	0.4	0.176	66.37	16,383	
		1	5	0.4	0.137	46.13	12,851	
		1	6	0.4	0.189	73.74	17,576	
		3	7	0.3	0.154	2.07	1,622	
		3	8	0.3	0.106	1.21	1,132	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
438	Explosive, vulcan powder No. 1; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Wire rope bale parted, letting ring down.	1	1	0.4	0.161	58.41	15,044	
		1	2	0.4	0.201	81.13	18,729	
		1	3	0.4	0.172	64.18	16,018	
		1	4	0.4	0.186	72.08	17,309	
		1	5	0.4	0.149	51.34	13,949	
		1	6	0.4	0.156	55.70	14,375	
		3	7	0.3	0.153	2.05	1,610	
		3	8	0.3	0.041	0.35	494	
439	Explosive, vulcan powder No. 2; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 70 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.049	11.71	5,127	
		1	2	0.4	0.106	......	......	Hammered.
		1	3	0.4	0.073	19.42	7,218	
		1	4	0.4	0.070	18.42	6,971	
		1	5	0.4	0.060	15.15	6,119	
		1	6	0.4	0.070	18.42	6,971	
		3	7	0.3	0.019	0.11	234	
		3	8	0.3	0.046	0.39	535	
440	Explosive, vulcan powder No. 2; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Buoy rose 5 feet in a dome 3 feet high.	1	1	0.4	0.198	79.16	18,423	
		1	2	0.4	0.212	88.42	19,832	
		1	3	0.4	0.161	58.41	15,044	
		1	4	0.4	0.194	76.64	18,029	
		1	5	0.4	0.147	50.73	13,768	
		1	6	0.4	0.191	74.88	17,756	
		3	7	0.3	0.049	0.43	567	
		3	8	0.3	0.114	1.33	1,208	
441	Explosive, vulcan powder No. 2; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 70 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.076	20.46	7,473	
		1	2	0.4	0.104	31.29	9,904	
		1	3	0.4	0.074	19.75	7,300	
		1	4	0.4	0.072	19.08	7,135	
		1	5	0.4	0.052	12.62	5,395	
		1	6	0.4	0.049	11.71	5,127	
		3	7	0.3	0.024	0.17	304	
		3	8	0.3	0.038	0.31	463	
442	Explosive, vulcan powder No. 2; ring, 4 foot; charge, 2 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 1, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.114	35.38	10,768	
		1	2	0.4	0.144	49.60	13,492	
		1	3	0.4	0.099	29.13	9,460	
		1	4	0.4	0.109	33.22	10,328	
		1	5	0.4	0.092	26.32	8,841	
		1	6	0.4	0.088	24.82	8,502	
		3	7	0.3	0.037	0.30	451	
		3	8	0.3	0.078	0.79	856	
443	Explosive, vulcan powder No. 2; ring, 4 foot: charge, 2 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 1, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Buoy rose 2 feet; sunk out of sight; then began an upward boiling of the water.	1	1	0.4	0.129	......	......	Lead oblique.
		1	2	0.4	0.149	51.34	13,949	
		1	3	0.4	0.111	34.06	10,501	
		1	4	0.4	0.114	35.38	10,768	
		1	5	0.4	0.086	24.07	8,330	
		1	6	0.4	0.093	26.69	8,925	
		3	7	0.3	0.051	0.45	588	
		3	8	0.3	0.072	0.72	803	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
444	Explosive, vulcan powder No. 2; ring, 4 foot; charge, 3 pounds; submergence, 35 feet: depth of water, 70 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Effects: Buoy rose 3 feet; large boil.	1	1	0.4	0.149	51.34	13,949	
		1	2	0.4	0.145	50.12	13,587	
		1	3	0.4	0.145	50.12	13,587	
		1	4	0.4	0.140	47.52	13,113	
		1	5	0.4	0.106	32.02	10,076	
		1	6	0.4	0.138	46.59	12,939	
		3	7	0.3	0.042	0.36	502	
		3	8	0.3	0.054	0.49	620	
445	Explosive, vulcan powder No. 2; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.141	48.04	13,208	
		1	2	0.4	0.137	46.13	12,851	
		1	3	0.4	0.139	47.06	13,026	
		1	4	0.4	6.144	49.60	13,492	
		1	5	0.4	0.116	36.27	10,947	
		1	6	0.4	0.135	45.20	12,677	
		3	7	0.3	0.062	0.60	708	
		3	8	0.3	0.009	0.68	776	
446	Explosive, vulcan powder No. 2; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Crack appeared in suspension strap; changed it.	1	1	0.4	0.160	57.90	14,957	
		1	2	0.4	0.135	......	......	Gauge jammed.
		1	3	0.4	0.149	51.34	13,949	
		1	4	0.4	0.143	49.08	13,397	
		1	5	0.4	0.136	45.66	12,764	
		1	6	0.4	0.139	47.06	13,026	
		3	7	0.3	0.097	1.07	1,044	
		3	8	0.3	0.047	0.40	546	
447	Explosive, vulcan powder No. 2; ring, 4 foot; charge, 4 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.143	49.08	13,397	
		1	2	0.4	0.166	60.96	15,479	
		1	3	0.4	0.153	54.15	14,304	
		1	4	0.4	0.134	44.67	12,578	
		1	5	0.4	0.155	55.15	14,480	
		1	6	0.4	0.167	61.50	15,569	
		3	7	0.3	0.060	0.58	695	
		3	8	0.3	0.101	1.13	1,081	
448	Explosive, vulcan powder No. 2; ring, 4 foot; charge, 5 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: A three foot dome.	1	1	0.4	0.180	68.67	16,757	
		1	2	0.4	0.150	......	......	Jammed badly.
		1	3	0.4	0.167	61.50	15,569	
		1	4	0.4	0.181	69.24	16,850	
		1	5	0.4	0.154	54.65	14,392	
		1	6	0.4	0.185	71.52	17,220	
		3	7	0.3	0.063	0.60	714	
		3	8	0.3	0.116	1.36	1,227	
449	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Small dome, as usual.	1	1	0.4	0.246	113.50	23,428	
		1	2	0.4	0.210	87.00	19,620	
		1	3	0.4	0.135	45.20	12,677	
		1	4	0.4	0.169	62.57	15,748	
		1	5	0.4	0.131	43.09	12,282	
		1	6	0.4	0.143	49.08	13,397	
		3	7	0.3	0.049	0.43	567	
		3	8	0.3	0.106	1.21	1,132	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
450	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 70 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.192	75.47	17,847	
		1	2	0.4	0.194	76.64	18,029	
		1	3	0.4	0.141	48.04	13,208	
		1	4	0.4	0.167	61.50	15,569	
		1	5	0.4	0.141	48.04	13,208	
		1	6	0.4	0.150	52.64	14,040	
		3	7	0.3	0.086	0.92	943	
		3	8	0.3	0.109	1.25	1,162	
451	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water. 70 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.173	64.72	16,109	
		1	2	0.4	0.216	91.28	20,258	
		1	3	0.4	0.166	60.96	15,479	
		1	4	0.4	0.168	62.03	15,658	
		1	5	0.4	0.121	38.52	11,398	
		1	6	0.4	0.142	48.56	13,303	
		3	7	0.3	0.096	1.05	1,035	
		3	8	0.3	0.095	1.04	1,026	
452	Explosive, dynamite No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 70 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. Gauges 1, 3, 5, pins 2.35 inches long; gauges, 2, 4, 6, pins 1.5 inches long. Effects: Normal.	1	1	0.3	0.138	29.01	9,435	
		1	2	0.3	0.189	47.02	13,020	
		1	3	0.3	0.105	19.67	7,283	
		1	4	0.3	0.128	26.02	8,773	
		1	5	0.3	0.077	13.00	5,523	
		1	6	0.3	0.072	11.86	5,197	
		3	7	0.3	0.080	0.82	876	
		3	8	0.3	0.048	0.42	556	
453	Explosive, dynamite No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 70 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. Gauges 1, 3, 5, pins 2.35 inches long; gauges 2, 4, 6, pins 1.5 inches long. Effects: Normal.	1	1	0.3	0.170	39.86	11,660	
		1	2	0.3	0.146	31.52	9,973	
		1	3	0.3	0.115	22.32	7,924	
		1	4	0.3	0.136	28.39	9,300	
		1	5	0.3	0.068	11.00	4,943	
		1	6	0.3	0.094	17.04	6,615	
		3	7	0.3	0.063	0.60	714	
		3	8	0.3	0.067	0.65	751	
454	Explosive, dynamite No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 70 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. Gauges 1, 3, 5, pins 2.35 inches long; gauges 2, 4, 6, pins 1.5 inches long. Effects: Normal.	1	1	0.3	0.161	36.71	11,035	
		1	2	0.3	0.143	30.56	9,769	
		1	3	0.3	0.132	27.19	9,034	
		1	4	0.3	0.134	27.78	9,166	
		1	5	0.3	0.074	12.30	5,323	
		1	6	0.3	0.098	19.09	6,886	
		3	7	0.3	0.068	0.67	764	
		3	8	0.3	0.076	0.76	835	
455	Explosive, dynamite No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 70 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. All gauge pins 2.35 inches long, *i. e.*, flush with face of plug. Effects: Normal.	1	1	0.3	0.174	41.31	11,944	
		1	2	0.3	0.128	26.02	8,773	
		1	3	0.3	0.122	24.31	8,386	
		1	4	0.3	0.123	24.60	8,450	
		1	5	0.3	0.078	13.23	5,591	
		1	6	0.3	0.086	15.06	6,093	
		3	7	0.3	0.061	0.59	701	
		3	8	0.3	0.069	0.68	776	

Details of experiments with the Rings—Continued.

Original num-	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
456	Explosive, dynamite No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 70 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. All gauge-pins 2.35 inches long. Effects: Normal.	1	1	0. 3	0. 104	19. 43	7, 224	
		1	2	0. 3	0. 113	21. 78	7, 794	
		1	3	0. 3	0. 120	23. 75	8, 256	
		1	4	0. 3	0. 113	21. 78	7, 794	
		1	5	0. 3	0. 220	59. 38	15, 217	
		1	6	0. 3	0. 096	17. 88	6, 741	
		3	7	0. 3	0. 077	0. 78	845	
		3	8	0. 3	0. 108	1. 24	1, 152	
457	Explosive, dynamite No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 70 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. All gauge-pins 2.35 inches long. Effects: Normal.	1	1	0. 3	0. 166	38. 46	11, 384	
		1	2	0. 3	0. 122	24. 31	8, 386	
		1	3	0. 3	0. 128	26. 02	8, 773	
		1	4	0. 3	0. 120	23. 75	8, 256	
		1	5	0. 3	0. 071	11. 64	5, 133	
		1	6	0. 3	0. 090	16. 05	6, 357	
		3	7	0. 3	0. 044	0. 37	517	
		3	8	0. 3	0. 090	0. 98	986	
458	Explosive, dynamite No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 50 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0. 3	0. 095	17. 28	6, 679	
		1	2	0. 3	0. 188	46. 62	12, 947	
		1	3	0. 3	0. 110	20. 96	7, 599	
		1	4	0. 3	0. 124	24. 88	8, 515	
		1	5	0. 3	0. 094	17. 04	6, 615	
		1	6	0. 3	0. 094	17. 04	6, 615	
		3	7	0. 3	0. 021	0. 13	258	
		3	8	0. 3	0. 040	0. 34	487	
459	Explosive, dynamite No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 50 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0. 3	0. 125	25. 16	8, 580	
		1	2	0. 3	0. 134	27. 78	9, 166	
		1	3	0. 3	0. 117	22. 89	8. 057	
		1	4	0. 3	0. 110	20. 96	7, 599	
		1	5	0. 3	0. 102	18. 97	7, 107	
		1	6	0. 3	0. 084	14. 59	5, 967	
		3	7	0. 3	0. 030	0. 22	364	
		3	8	0. 3	0 070	0. 70	788	
460	Explosive, dynamite No. 1; ring, 4 foot; charge, 1 pound; submergence, 35 feet; depth of water, 50 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0. 3	0. 112	21. 50	7, 729	
		1	2	0. 3	0. 174	41. 31	11, 944	
		1	3	0. 3	0. 110	20. 96	7, 599	
		1	4	0. 3	0. 115	22. 32	7, 924	
		1	5	0. 3	0. 099	19. 70	6, 928	
		1	6	0. 3	0. 093	16. 79	6, 550	
		3	7	0. 3	0. 046	0. 39	535	
		3	8	0. 3	0. 077	0. 78	845	
461	Explosive, dynamite No. 1, vulcan powder No. 1; ring, 4 foot; charge, 1.5 + 1.5 pounds; submergence, 35 feet; depth of water, 50 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Effects: Buoy rose 3 feet; dome 6 inches high.	1	1	0. 4	0. 147	50. 73	13, 768	
		1	2	0. 4	0. 165	60. 43	15, 390	
		1	3	0. 4	0. 146	50. 42	13, 678	
		1	4	0. 4	0. 147	50. 73	13, 768	
		1	5	0. 4	0. 135	45. 20	12, 677	
		1	6	0. 4	0. 126	40. 85	11, 853	
		3	7	0. 3	0. 082	0. 85	898	
		3	8	0. 3	0. 091	0. 99	994	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
462	Explosive, dynamite No. 1, vulcan powder No. 1; ring, 4 foot; charge, 1.5+1.5 pounds; submergence, 35 feet; depth of water, 50 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.156	55.70	14,575	
		1	2	0.4	0.143	49.08	13,397	
		1	3	0.4	0.167	61.50	15,569	
		1	4	0.4	0.167	61.50	15,569	
		1	5	0.4	0.143	49.08	13,397	
		1	6	0.4	0.147	50.73	13,768	
		3	7	0.3	0.071	0.71	795	
		3	8	0.3	0.110	1.27	1,172	
463	Explosive, dynamite No. 1. vulcan powder No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 50 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.141	48.04	13,208	
		1	2	0.4	0.133	44.14	12,479	
		1	3	0.4	0.147	50.73	13,768	
		1	4	0.4	0.143	49.08	13,397	
		1	5	0.4	0.132	43.62	12,381	
		1	6	0.4	0.155	55.15	14,480	
		3	7	0.3	0.083	0.87	910	
		3	8	0.3	0.106	1.21	1,132	
464	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 50 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.148	51.03	13,850	
		1	2	0.4	0.188	73.19	17,487	
		1	3	0.4	0.159	57.35	14,862	
		1	4	0.4	0.166	60.96	15,479	
		1	5	0.4	0.129	42 13	12,100	
		1	6	0.4	0.146	50.42	13,678	
		3	7	0.3	0.088	0.95	964	
		3	8	0.3	0.086	0.92	943	
465	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 50 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Same leads as in last shot, each in same gauge as before. Effects: Normal.	1	1	0.4	0.287	147.2	27,866	Same leads used as in shot 464.
		1	2	0.4	0.322	181.1	31,984	
		1	3	0.4	0.278	139.6	26,892	
		1	4	0.4	0.299	157.7	29,193	
		1	5	0.4	0.243	111.1	23,007	
		1	6	0.4	0.275	136.9	26,550	
		3	7	0.3	0.172	2.45	1,814	
		3	8	0.3	0.110	1.27	1,172	
466	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 50 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Same leads as in last shot, each in same gauge as before. Effects: Normal.	1	1	0.4	0.389	255.1	40,204	
		1	2	0.4	0.405	274.5	42,220	Same leads used as in shots 464 and 465.
		1	3	0.4	0.375	237.6	38,835	
		1	4	0.4	0.403	272.3	42,000	
		1	5	0.4	0.328	187.4	32,725	
		1	6	0.4	0.352	212.7	35,608	
		3	7	0.3	0.252	4.45	2,696	
		3	8	0.3	0.301	6.07	3,326	
467	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 50 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.235	105.10	22,255	
		1	2	0.4	0.182	69.81	16,942	
		1	3	0.4	0.165	60.43	15,390	
		1	4	0.4	0.170	63.10	15,837	
		1	5	0.4	0.137	46.13	12,851	
		1	6	0.4	0.150	52.64	14,040	
		3	7	0.3	0.085	0.90	932	
		3	8	0.3	0.109	1.25	1,162	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
468	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 50 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Same leads as in last shot; each in same gauge as before. Effects: Normal.	1	1	0.4	0.340	199.2	34,090	Same leads used as in last shot.
		1	2	0.4	0.322	181.1	31,984	
		1	3	0.4	0.287	147.2	27,866	
		1	4	0.4	0.315	173.8	31,120	
		1	5	0.4	0.231	102.1	21,835	
		1	6	0.4	0.262	126.3	25,156	
		3	7	0.3	0.164	2.27	1,727	
		3	8	0.3	0.203	3.13	2,135	
469	Explosive, dynamite No. 1; ring, 4 foot; charge, 3 pounds; submergence, 35 feet; depth of water, 50 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Same leads as in last shot; each in same gauge as before. Effects: Normal. Last shot of season; fired October 24, 1876.	1	1	0.4	0.529	461.2	59,660	Same leads used as in last shot.
		1	2	0.4	0.411	282.5	43,028	
		1	3	0.4	0.381	244.8	39,116	
		1	4	0.4	0.408	278.5	42,622	
		1	5	0.4	0.290	149.8	28,190	
		1	6	0.4	0.338	197.1	33,850	
		3	7	0.3	0.231	3.84	2,449	
		3	8	0.3	0.272	5.09	2,957	
470	Explosive, musket powder; ring, 3 foot; charge, 48 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 4, full; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Jet about 30 feet high. First shot of season; fired August 27, 1877.	1	1	0.4	0.114	13.07	5,544	
		1	2	0.4	0.084	8.63	4,204	
		1	3	0.4	0.122	14.42	5,918	
		1	4	0.4	0.127	15.26	6,148	
		1	5	0.4	0.114	13.07	5,544	
		1	6	0.4	0.098	10.61	4,824	
		3	7	0.3	0.075	0.03	94	
471	Explosive, musket powder; ring, 3 foot; charge, 48 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 4, full; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Jet rather larger than last.	1	1	0.4	0.132	16.12	6,376	
		1	2	0.4	0.084	8.63	4,204	
		1	3	0.4	0.119	13.90	5,775	
		1	4	0.4	0.136	16.88	6,575	
		1	5	0.4	0.124	14.67	6,015	
		1	6	0.4	0.094	10.01	4,641	
		3	7	0.3	0.076	0.03	95	
472	Explosive, musket powder; ring, 3 feet; charge, 48 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 4, full; ignition, Farmer dynamo, 1 service low tension fuze, and 4 ounces dynamite No. 1, in paper cylinder in centre of charge. Effects: Jet broader but not so high as last.	1	1	0.4	0.154	20.22	7,416	
		1	2	0.4	0.145	18.54	7,000	
		1	3	0.4	0.161	21.60	7,751	
		1	4	0.4	0.140	17.57	6,753	
		1	5	0.4	0.153	20.03	7,369	
		1	6	0.4	0.140	17.57	6,753	
		3	7	0.3	0.041	0.01	56	
473	Explosive, musket powder; ring, 3 feet; charge, 48 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 4, full; ignition, Farmer dynamo, 1 service low tension fuze, and 4 ounces of dynamite No. 1, in paper cylinder in centre of charge. Effects: Jet rather larger than last.	1	1	0.4	0.163	21.97	7,840	
		1	2	0.4	0.159	21.21	7,657	
		1	3	0.4	0.175	24.32	8,388	
		1	4	0.4	0.165	22.35	7,929	
		1	5	0.4	0.159	21.21	7,657	
		1	6	0.4	0.149	19.27	7,184	
		3	7	0.4	0.036	0.01	49	
474	Explosive, musket powder; ring, 3 feet; charge, 48 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 4, full; ignition, Farmer dynamo, 1 Abel gun-cotton fuze, and 4 ounces of dry compressed gun-cotton in centre of charge. Effects: Jet decidedly larger and higher than last; recovered fragment of can 6 inches square; it was grooved by powder grains.	1	1	0.4	0.203	30.48	9,752	
		1	2	0.4	0.204	30.73	9,805	
		1	3	0.4	0.204	30.73	9,805	
		1	4	0.4	0.219	34.55	10,600	
		1	5	0.4	0.175	24.32	8,388	
		1	6	0.4	0.184	28.22	8,820	
		3	7	0.3	0.067	0.03	86	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
475	Explosive, musket powder; ring, 3 foot; charge, 48 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 4, full; ignition, Farmer dynamo, 1 Abel gun-cotton fuze, and 4 ounces of dry compressed gun-cotton in centre of charge. Effects: Jet higher than last; No. 3 gauge socket struck by buoy.	1	1	0.4	0.219	34.55	10,600	
		1	2	0.4	0.192	27.89	9,190	
		1	3	0.4	0.212	32.68	10,216	
		1	4	0.4	0.241	40.52	11,787	
		1	5	0.4	0.176	24.53	8,436	
		1	6	0.4	0.216	33.74	10,435	
		3	7	0.3	0.057	0.02	75	
476	Explosive, dynamite No. 1; ring, 3 foot; charge, ½ pound; submergence, 33 feet; depth of water, 82 feet; case, tin cylinder, 1 inch by 6 inches; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Shock tipped over a can in boat, 80 feet from vertical through charge; only a few bubbles of gas rose to the surface.	1	1	0.4	0.055	13.50	5,666	
		1	2	0.4	0.059	14.82	6,028	
		1	3	0.4	0.020	.....	......	Water in gauge.
		1	4	0.4	0.042	9.64	4,524	
		1	5	0.4	0.042	9.64	4,524	
		1	6	0.4	0.042	9.64	4,524	
		3	7	0.3	0.009	0.05	143	
477	Explosive, dynamite No. 1; ring, 3 foot; charge, ½ pound; submergence, 33 feet; depth of water, 82 feet; case, tin cylinder, 1 inch by 6 inches; ignition, Farmer dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.051	12.32	5,305	
		1	2	0.4	0.076	20.46	7,473	
		1	3	0.4	0.043	9.91	4,608	
		1	4	0.4	0.044	10.18	4,692	
		1	5	0.4	0.039	8.81	4,264	
		1	6	0.4	0.043	9.91	4,608	
		3	7	0.3	0.002	0.01	52	
478	Fired near iron target.—See Appendix C.							
479	Explosive, picrate powder No. 0; ring, 3 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 70 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Effects: Strong explosion, followed by a boil; effect much more than was anticipated.	3	1	0.3	.....	.....	......	Leads compressed to such an extent as to be worthless.
		3	2	0.3	.....	.....	......	
		3	3	0.3	.....	.....	......	
		3	4	0.3	.....	.....	......	
		3	5	0.3	.....	.....	......	
		3	6	0.3	.....	.....	......	
		3	7	0.3	0.008	0.05	135	
480	Explosive, picrate powder No. 1; ring, 3 foot; charge, 2.9 pounds; submergence, 33 feet; depth of water, 70 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Effects: Buoy rose 4 feet; boil tinged green.	1	1	0.4	0.160	57.90	14,957	
		1	2	0.4	0.088	24.82	8,502	
		1	3	0.4	0.094	27.07	9.009	
		1	4	0.4	0.086	24.07	8,330	
		1	5	0.4	0.088	24.82	8,502	
		1	6	0.4	0.079	21.58	7,745	
		3	7	0.3	0.054	0.49	620	
481	Explosive, picrate powder No. 2; ring, 3 foot; charge, 2.9 pounds; submergence, 33 feet; depth of water, 70 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Effects: Buoy rose 5 feet; boil green, as before.	1	1	0.4	0.076	20.46	7,473	
		1	2	0.4	0.082	22.65	7,999	
		1	3	0.4	0.054	13.21	5,576	
		1	4	0.4	0.056	13.83	5,757	
		1	5	0.4	0.051	12.32	5,305	
		1	6	0.4	0.029	6.10	3,336	
		3	7	0.3	0.043	0.36	509	
482	Explosive, picrate powder No. 3; ring, 3 foot; charge, 2.9 pounds; submergence, 33 feet; depth of water, 70 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Effects: Buoy rose 2½ feet; boil less than before.	1	1	0.4	0.038	8.53	4,172	
		1	2	0.4	0.027	5.59	3,145	
		1	3	0.4	0.010	1.73	1,440	
		1	4	0.4	0.011	1.93	1,548	
		1	5	0.4	0.007	1.17	1,110	
		1	6	0.4	0.012	2.13	1,651	
		3	7	0.3	0.006	0.04	109	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
483	Explosive, dynamite No. 1; ring, 3 foot; charge, 1 pound; submergence, 33 feet; depth of water, 70 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. Effects: Gauge No. 8 attached to ring by a 2-inch pine plank near No. 3 gauge; distance from charge the same. It was secured by a 10-foot length of wire rope shackled to guard ring.	1	1	0.4	0.167	61.50	15,569	
		1	2	0.4	0.195	77.22	18,120	
		1	3	0.4	0.137	46.13	12,851	
		1	4	0.4	0.123	39.47	11,584	
		1	5	0.4	0.111	34.06	10,501	
		1	6	0.4	0.100	29.55	9,552	
		3	7	0.3	0.051	0.45	588	
		1	8	0.4	0.019	3.65	2,362	Extra gauge.
484	Explosive, dynamite No. 1; ring, 3 foot; charge, 1 pound; submergence, 33 feet; depth of water, 70 feet; case, fuze can; ignition, Smith dynamo, 1 service, low tension fuze. Effects: Gauge No. 8 attached as in last shot. Wood attachment broken in small fragments by explosion, and so compressed as to have little flotation left.	1	1	0.4	0.149	51.34	13,949	
		1	2	0.4	0.163	59.42	15,217	
		1	3	0.4	0.134	44.67	12,578	
		1	4	0.4	0.128	41.70	12,018	
		1	5	0.4	0.109	33.22	10,328	
		1	6	0.4	0.107	32.42	10,160	
		3	7	0.3	0.058	0.55	669	
		1	8	0.4	0.039	8.81	4,264	Extra gauge.
485	Explosive, dynamite No. 1; ring, 3 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 70 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Effects: Same remarks as for last two shots. Gauge lost by breaking of bale of socket by the jerk on wire rope; corrected defect by a rope wrapping round bale.	1	1	0.4	0.209	86.37	19,525	
		1	2	0.4	0.303	161.80	29,682	
		1	3	0.4	0.190	74.30	17,665	
		1	4	0.4	0.193	76.05	17,938	
		1	5	0.4	0.186	72.08	17,309	
		1	6	0.4	0.202	81.81	18,833	
		3	7	0.3	0.108	1.24	1,152	
		1	8	0.4	......	......	......	Lost gauge.
486	Explosive, dynamite No. 1; ring, 3 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 70 feet; case, can No. 1; ignition, Smith dynamo, 1 service, low tension fuze. Effects: Same remarks as for shots 483 and 484.	1	1	0.4	0.197	78.52	18,322	
		1	2	0.4	0.242	110.40	22,898	
		1	3	0.4	0.207	85.10	19,335	
		1	4	0.4	0.199	79.81	18,524	
		1	5	0.4	0.196	77.87	18,221	
		1	6	0.4	0.214	89.84	20,044	
		3	7	0.3	0.099	1,10	1,062	
		1	8	0.4	0.018	3.42	2,261	Extra gauge.
487	Explosive, dynamite No. 1; ring, 3 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 70 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze; Effects: Same remarks as for shots 483 and 484. Lowering rope parted by explosion; ring held by suspension rope.	1	1	0.4	0.293	152.40	28,511	
		1	2	0.4	0.320	179.00	31,740	
		1	3	0.4	0.264	128.00	25,382	
		1	4	0.4	0.272	134.40	26,226	
		1	5	0.4	0.214	89.81	20,044	
		1	6	0.4	0.234	104.40	22,150	
		3	7	0.3	0.157	2.13	1,656	
		1	8	0.4	0.024	4.84	2,855	Extra gauge.
488	Explosive, dynamite No. 1; ring, 3 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 70 feet; case, can No. 1; ignition, Smith dynamo, 1 service low tension fuze. Effects: Same remarks as for shots 483 and 484. Last shot of season; fired on September 27, 1877.	1	1	0.4	0.296	155.0	28,842	
		1	2	0.4	0.389	......	......	Hammered.
		1	3	0.4	0.280	141.4	27,120	
		1	4	0.4	0.260	124.6	24,930	
		1	5	0.4	0.219	93.5	20,582	
		1	6	0.4	0.252	118.1	24,056	
		3	7	0.3	0.178	2.55	1,867	
		1	8	0.4	0.019	3.65	2,362	Extra gauge.

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
489	Explosive, dynamite No. 1, loose; ring, 8 foot; charge, 8 pounds; submergence, 46 feet; depth of water, 72 feet; case, can No. 2; ignition, Smith dynamo, 1 service low tension fuze. Effects: A ten-foot jet; many fish killed at great distances. First shot of season; fired on June 19, 1878.	1	1	0.4	0.094	27.07	9,009	
		1	2	0.4	0.222	95.62	20,898	
		1	3	0.4	0.065	16.73	6,537	
		1	4	0.4	0.068	17.74	6,797	
		1	5	0.4	0.047	11.08	4,952	
		1	6	0.4	0.048	11.39	5,039	
		3	7	0.3	0.132	1.64	1,387	
490	Explosive, dynamite No. 1, loose; ring, 8 foot; charge, 8 pounds; submergence, 44 feet; depth of water, 72 feet; case, can No. 2, full; ignition, Smith dynamo, 1 service low tension fuze. Effects: Dome, 5 feet high.	1	1	0.4	0.153	54.15	14,304	
		1	2	0.4	0.139	47.06	13,026	
		1	3	0.4	0.070	18.42	6,971	
		1	4	0.4	0.071	18.75	7,053	
		1	5	0.4	0.077	20.83	7,564	
		1	6	0.4	0.074	19.75	7,300	
		3	7	0.3	0.141	1.79	1,473	
491	Explosive, dynamite No. 1, loose; ring, 8 foot; charge, 8 pounds; submergence, 44 feet; depth of water, 72 feet; case, can No. 2, full; ignition, Smith dynamo, 1 service low tension fuze. Effects: Ring began to warp a little.	1	1	0.4	0.145	50.12	13,587	
		1	2	0.4	0.087	24.44	8,416	
		1	3	0.4	0.077	20.83	7,564	
		1	4	0.4	0.063	16.10	6,370	
		1	5	0.4	0.070	18.42	6,971	
		1	6	0.4	0.075	20.08	7,382	
		3	7	0.3	0.165	2.29	1,736	
492	Explosive, dynamite No. 1, loose; ring, 8 foot; charge, 8 pounds; submergence, 44 feet; depth of water, 72 feet; case, can No. 2, full; ignition, Smith dynamo, 1 service low tension fuze. Effects: A 5-foot boil; buoy shot up 4 feet; warp in ring increasing near top.	1	1	0.4	0.110	33.62	10,412	
		1	2	0.4	0.099	29.13	9,460	
		1	3	0.4	0.076	20.46	7,478	
		1	4	0.4	0.074	19.75	7,300	
		1	5	0.4	0.072	19.08	7,135	
		1	6	0.4	0.056	13.83	5,757	
		3	7	0.3	0.161	2.22	1,699	
493	Explosive, dynamite No. 1; ring 8 foot; charge, 8 pounds; submergence, 44 feet; depth of water, 72 feet; case, can No. 2, full; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.104	31.29	9,904	
		1	2	0.4	0.115	35.82	10,857	
		1	3	0.4	0.080	21.96	7,836	
		1	4	0.4	0.081	22.31	7,918	
		1	5	0.4	0.060	15.15	6,119	
		1	6	0.4	0.067	17.41	6,711	
		3	7	0.3	0.135	1.69	1,418	
494	Explosive, dynamite No. 1; ring, 8 foot; charge, 8 pounds; submergence, 44 feet; depth of water, 72 feet; case, can No. 4, mostly air space; ignition, Smith dynamo, 1 service low tension fuze. Effects: Warp is now 5¼ inches on line between gauges 1 and 2, and increasing.	1	1	0.4	0.067	17.41	6,711	
		1	2	0.4	0.050	12.03	5,215	
		1	3	0.4	0.056	13.83	5,757	
		1	4	0.4	0.048	11.39	5,039	
		1	5	0.4	0.052	12.62	5,395	
		1	6	0.4	0.049	11.71	5,127	
		3	7	0.3	0.167	2.34	1,760	
495	Explosive, dynamite No. 1; ring, 8 foot; charge, 8 pounds; submergence, 44 feet; depth of water, 72 feet; case, can No. 4, mostly air space; ignition, Smith dynamo, 1 service low tension fuze. Effects: Buoy rose less and boil was smaller than before.	1	1	0.4	0.118	37.16	11,126	
		1	2	0.4	0.061	15.47	6,203	
		1	3	0.4	0.052	12.62	5,395	
		1	4	0.4	0.056	13.83	5,757	
		1	5	0.4	0.059	14.82	6,028	
		1	6	0.4	0.044	10.18	4,692	
		3	7	0.3	0.166	2.31	1,748	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
496	Explosive, dynamite No. 1; ring, 8 foot; charge, 10 pounds; submergence, 44 feet; depth of water, 72 feet; case, can No. 2, full, compressed; ignition, Smith dynamo, 1 service low tension fuze. Effects: Warp measures 6½ inches after this shot.	1	1	0.4	0.117	36.71	11,036	
		1	2	0.4	0.117	36.71	11,036	
		1	3	0.4	0.084	23.34	8,162	
		1	4	0.4	0.072	19.08	7,135	
		1	5	0.4	0.079	21.58	7,745	
		1	6	0.4	0.081	22.81	7,918	
		3	7	0.3	0.172	2.45	1,814	
497	Explosive, dynamite No. 1; ring, 8 foot; charge, 10 pounds; submergence, 44 feet; depth of water, 72 feet; case, can No. 2, compressed; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.102	30.42	9,728	
		1	2	0.4	0.079	21.58	7,745	
		1	3	0.4	0.082	22.65	7,999	
		1	4	0.4	0.089	25.19	8,588	
		1	5	0.4	0.084	23.34	8,162	
		1	6	0.4	0.079	21.58	7,745	
		3	7	0.3	0.166	2.31	1,748	
498	Explosive, dynamite No. 1; ring, 8 foot; charge, 10 pounds; submergence, 44 feet; depth of water, 72 feet; case, can No. 2, compressed; ignition, Smith dynamo, 1 service low tension fuze. Effects: Warp measures 7 inches before and 8 inches after this shot; it is on vertical, both top and bottom.	1	1	0.4	0.099	29.13	9,460	
		1	2	0.4	0.094	27.07	9,009	
		1	3	0.4	0.092	26.32	8,841	
		1	4	0.4	0.089	25.19	8,588	
		1	5	0.4	0.074	19.75	7,300	
		1	6	0.4	0.084	23.34	8,162	
		3	7	0.3	0.183	2.68	1,928	
499	Explosive, dynamite No. 1; ring, 8 foot; charge, 10 pounds; submergence, 44 feet; depth of water, 72 feet; case, can No. 2, compressed; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.086	24.07	8,330	
		1	2	0.4	0.090	25.57	8,674	
		1	3	0.4	0.088	24.82	8,502	
		1	4	0.4	0.070	18.42	6,971	
		1	5	0.4	0.085	23.69	8,244	
		1	6	0.4	0.079	21.58	7,745	
		3	7	0.3	0.160	2.20	1,690	
500	Explosive, dynamite No. 1; ring, 8 foot; charge, 10 pounds; submergence, 44 feet; depth of water, 72 feet; case, can No. 2, compressed; ignition, Smith dynamo, 1 service low tension fuze. Effects: Warp, 10½ inches before and 12½ inches after this shot; ring decidedly too large for the best class of work.	1	1	0.4	0.069	18.08	6,884	
		1	2	0.4	0.092	26.32	8,841	
		1	3	0.4	0.084	23.34	8,162	
		1	4	0.4	0.100	29.55	9,552	
		1	5	0.4	0.079	21.58	7,745	
		1	6	0.4	0.078	21.21	7,654	
		3	7	0.3	0.141	1.79	1,473	
501	Explosive, dynamite No. 1; ring, 5 foot; charge, 1 pound; submergence, 23 feet; depth of water, 79 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.076	20.46	7,473	
		1	2	0.4	0.064	16.42	6,453	
		1	3	0.4	0.046	10.76	4,864	
		1	4	0.4	0.034	7.41	3,803	
		1	5	0.4	0.039	8.81	4,261	
		1	6	0.4	0.024	4.84	2,855	
		3	7	0.3	0.081	0.84	887	
502	Explosive, dynamite No. 1; ring, 5 foot; charge, 1 pound; submergence, 23 feet; depth of water, 79 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.064	16.42	6,453	
		1	2	0.4	0.061	15.47	6,203	
		1	3	0.4	0.050	12.08	5,215	
		1	4	0.4	0.038	8.53	4,172	
		1	5	0.4	0.042	9.64	4,524	
		1	6	0.4	0.026	5.34	3,049	
		3	7	0.3	0.084	0.88	921	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
503	Explosive, dynamite No. 1; ring, 5 foot; charge, 1 pound; submergence, 23 feet; depth of water, 79 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0. 4	0. 058	14. 49	5, 938	
		1	2	0. 4	0. 067	17. 41	6, 711	
		1	3	0. 4	0. 042	9. 64	4, 524	
		1	4	0. 4	0. 040	9. 10	4, 356	
		1	5	0. 4	0. 041	9. 37	4, 440	
		1	6	0. 4	0. 025	5. 08	2, 954	
		3	7	0. 3	0. 107	1. 22	1, 142	
504	Explosive, dynamite No. 1; ring, 5 foot; charge, 1 pound; submergence, 23 feet; depth of water, 79 feet; case, fuze can; ignition, Smith dynamo, 1 service low tension fuse. Effects: Normal.	1	1	0. 4	0. 055	13. 50	5, 666	
		1	2	0. 4	0. 062	15. 78	6, 286	
		1	3	0. 4	0. 044	10. 18	4, 692	
		1	4	0. 4	0. 040	9. 10	4, 356	
		1	5	0. 4	0. 029	6. 10	3, 336	
		1	6	0. 4	0. 030	6. 36	3, 431	
		3	7	0. 3	0. 108	1. 24	1, 152	
505	Explosive, dynamite, No. 1; ring, 5 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 1, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0. 4	0. 099	29. 13	9, 460	
		1	2	0. 4	0. 160	57. 90	14, 957	
		1	3	0. 4	0. 089	25. 19	8, 588	
		1	4	0. 4	0. 079	21. 58	7, 745	
		1	5	0. 4	0. 069	18. 08	6, 884	
		1	6	0. 4	0. 061	15. 47	6, 203	
		3	7	0. 3	0. 162	2. 24	1, 708	
506	Explosive, dynamite No. 1; ring, 5 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 1, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0. 4	0. 119	37. 60	11, 215	
		1	2	0. 4	0. 125	40. 42	11, 770	
		1	3	0. 4	0. 078	21. 21	7, 654	
		1	4	0. 4	0. 070	18. 42	6, 971	
		1	5	0. 4	0. 076	20. 46	7, 473	
		1	6	0. 4	0. 052	12. 62	5, 395	
		3	7	0. 3	0. 095	1. 04	1, 026	
507	Explosive, dynamite No. 1; ring, 5 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 1, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0. 4	0. 156	55. 70	14, 575	
		1	2	0. 4	0. 176	66. 37	16, 383	
		1	3	0. 4	0. 093	26. 69	8, 925	
		1	4	0. 4	0. 078	21. 21	7, 654	
		1	5	0. 4	0. 069	18. 08	6, 884	
		1	6	0. 4	0. 061	15. 47	6, 203	
		3	7	0. 3	0. 177	2. 54	1, 859	
508	Explosive, dynamite No. 1; ring, 5 foot: charge, 2 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 1, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0. 4	0. 117	36. 71	11, 036	
		1	2	0. 4	0. 111	34. 06	10, 501	
		1	3	0. 4	0. 082	22. 65	7, 999	
		1	4	0. 4	0. 065	16. 73	6, 537	
		1	5	0. 4	0. 056	13. 83	5, 757	
		1	6	0. 4	0. 051	12. 32	5, 305	
		3	7	0. 3	0. 151	2. 00	1, 587	
509	Explosive, dynamite No. 1; ring, 5 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 1, full; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0. 4	0. 163	59. 42	15, 217	
		1	2	0. 4	0. 152	53. 64	14 216	
		1	3	0. 4	0. 121	38. 52	11, 396	
		1	4	0. 4	0. 085	23. 69	8, 244	
		1	5	0. 4	0. 111	34. 06	10, 501	
		1	6	0. 4	0. 074	19. 75	7, 300	
		3	7	0. 3	0. 211	3. 31	2, 221	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
510	Explosive, dynamite No. 1; ring, 5 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 1, full; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.156	55.70	14,575	
		1	2	0.4	0.159	57.35	14,862	
		1	3	0.4	0.119	37.60	11,215	
		1	4	0.4	0.096	27.86	9,184	
		1	5	0.4	0.090	25.57	8,674	
		1	6	0.4	0.098	28.71	9,368	
		3	7	0.3	0.118	1.39	1,248	
511	Explosive, dynamite No. 1; ring, 5 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 1, full; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.145	50.12	13,587	
		1	2	0.4	0.109	33.22	10,328	
		1	3	0.4	0.112	34.50	10,590	
		1	4	0.4	0.095	27.44	9,092	
		1	5	0.4	0.107	32.42	10,160	
		1	6	0.4	0.086	24.07	8,330	
		3	7	0.3	0.220	3.54	2,320	
512	Explosive, dynamite No. 1; ring, 5 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 1, full; ignition, Smith dynamo, 1 service low tension fuze. Effects: Boil 2 feet high.	1	1	0.4	0.154	54.65	14,392	
		1	2	0.4	0.165	60.43	15,390	
		1	3	0.4	0.117	36.71	11,036	
		1	4	0.4	0.080	21.96	7,836	
		1	5	0.4	0.095	27.44	9,092	
		1	6	0.4	0.096	27.86	9,184	
		3	7	0.3	0.132	1.64.	1,387	
513	Explosive, dynamite No. 1; ring, 5 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.182	69.81	16,942	
		1	2	0.4	0.166	60.96	15,479	
		1	3	0.4	0.133	44.14	12,479	
		1	4	0.4	0.121	38.52	11,398	
		1	5	0.4	0.131	43.09	12,282	
		1	6	0.4	0.115	35.82	10,857	
		3	7	0.3	0.159	2.18	1,679	
514	Explosive, dynamite No. 1; ring, 5 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.187	72.63	17,398	
		1	2	0.4	0.220	94.20	20,690	
		1	3	0.4	0.129	42.13	12,100	
		1	4	0.4	0.110	33.62	10,412	
		1	5	0.4	0.089	25.19	8,588	
		1	6	0.4	0.143	49.08	13,397	
		3	7	0.3	0.208	3.24	2,189	
515	Explosive, dynamite No. 1; ring, 5 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.219	93.47	20,582	
		1	2	0.4	0.205	83.84	19,145	
		1	3	0.4	0.129	42.13	12,100	
		1	4	0.4	0.106	32.02	10,076	
		1	5	0.4	0.106	32.02	10,076	
		1	6	0.4	0.110	33.62	10,412	
		3	7	0.3	0.207	3.22	2,178	
516	Explosive, dynamite No. 1; ring, 5 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.189	73.74	17,576	
		1	2	0.4	0.161	58.41	15,044	
		1	3	0.4	0.141	48.04	13,208	
		1	4	0.4	0.112	34.50	10,590	
		1	5	0.4	0.114	35.38	10,768	
		1	6	0.4	0.122	39.00	11,491	
		3	7	0.3	0.201	3.07	2,113	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
517	Explosive, dynamite No. 1; ring, 5 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuse. Effects: Normal.	1	1	0.4	0.165	60.43	15,390	
		1	2	0.4	0.166	60.96	15,479	
		1	3	0.4	0.143	49.08	13,397	
		1	4	0.4	0.123	39.47	11,584	
		1	5	0.4	0.128	41.70	12,018	
		1	6	0.4	0.131	43.09	12,282	
		3	7	0.3	0.160	2.20	1,690	
518	Explosive, dynamite No. 1; ring, 5 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuse. Effects: Normal.	1	1	0.4	0.121	38.52	11,398	
		1	2	0.4	0.165	60.43	15,390	
		1	3	0.4	0.155	55.15	14,480	
		1	4	0.4	0.131	43.09	12,282	
		1	5	0.4	0.150	52.64	14,040	
		1	6	0.4	0.147	50.73	13,768	
		3	7	0.3	0.125	1.51	1,316	
519	Explosive, dynamite No. 1; ring, 5 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.144	49.60	13,492	
		1	2	0.4	0.176	66.37	16,383	
		1	3	0.4	0.124	39.95	11,677	
		1	4	0.4	0.120	38.05	11,305	
		1	5	0.4	0.149	51.34	13,949	
		1	6	0.4	0.117	36.71	11,036	
		3	7	0.3	0.222	3.60	2,348	
520	Explosive, dynamite No. 1; ring, 5 foot; charge, 33 pounds; submergence, 79 feet; depth of water, 79 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuse. Effects: Bolt came out of a screw shackle, letting ring down.	1	1	0.4	0.129	42.13	12,100	
		1	2	0.4	0.149	51.34	13,949	
		1	3	0.4	0.131	43.09	12,282	
		1	4	0.4	0.114	35.38	10,768	
		1	5	0.4	0.137	46.13	12,851	
		1	6	0.4	0.114	35.38	10,768	
		3	7	0.3	0.224	3.67	2,376	
521	Explosive, dynamite No. 1; ring, 5 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 2, sawdust tamping; ignition, Smith dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.123	39.47	11,584	
		1	2	0.4	0.161	58.41	15,044	
		1	3	0.4	0.111	34.06	10,501	
		1	4	0.4	0.130	42.56	12,163	
		1	5	0.4	0.154	54.65	14,392	
		1	6	0.4	0.136	45.66	12,764	
		3	7	0.3	0.151	2.00	1,587	
522	Explosive, dynamite No. 1; ring, 8 foot; charge, 10 pounds; submergence, 35 feet; depth of water, 65 feet; case, can No. 2, full; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Ring had been restored to proper shape and reinforced at a weak spot. Effects: Jet 10 feet high.	1	1	0.4	0.114	35.38	10,768	
		1	2	0.4	0.112	34.50	10,590	
		1	3	0.4	0.093	26.69	8,925	
		1	4	0.4	0.091	25.94	8,758	
		1	5	0.4	0.087	24.44	8,416	
		1	6	0.4	0.095	27.44	9,092	
		3	7	0.3	0.145	1.87	1,517	
523	Explosive, dynamite No 1; ring, 8 foot; charge, 10 pounds; submergence, 35 feet; depth of water, 65 feet; case, can No. 2, full; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: At horizontal distance of 50 feet I felt, with hand in water, a sensation like electric shock simultaneously with the usual three sharp sounds and before the surface was disturbed.	1	1	0.4	0.092	26.32	8,841	
		1	2	0.4	0.097	28.28	9,276	
		1	3	0.4	0.096	27.86	9,184	
		1	4	0.4	0.085	23.69	8,244	
		1	5	0.4	0.089	25.19	8,588	
		1	6	0.4	0.090	25.57	8,674	
		3	7	0.3	0.147	1.91	1,552	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
524	Explosive, dynamite, No. 1; ring, 4 foot; charge, 500 pounds; submergence, 13 feet; depth of water, 20 feet; case, experimental torpedo of iron, 17 cubic feet; ignition, Gramme machine, 1 service low tension fuze. The buoy was shackled directly to ring and held by a 200 pound anchor at 130 feet from the charge. Effects: See page 44.	1	1	0. 3	0. 010	0. 94	959	
		1	2	0. 3	0. 003	.....	......	Spring out of order.
		1	3	0. 3	0. 008	0. 72	803	
		1	4	0. 3	0. 018	1. 30	1, 191	
		1	5	0. 3	0. 012	1. 18	1, 117	
		1	6	0. 3	0. 011	1. 06	1, 039	
		3	7	0. 3	0. 081	0. 84	887	
525	Explosive, gun-cotton, wet; ring, 4 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 75 feet; case, can No. 2, no tamping; ignition, Farmer dynamo, 1 Abel gun-cotton fuze, and 1 pound dry primer of gun-cotton. 25 per cent. of fresh water added to the charge of 4 pounds; the primer is included in the charge as reported, which is always exclusive of water.	1	1	0. 4	0. 210	87. 00	19, 620	
		1	2	0. 4	0. 214	89. 84	20, 044	
		1	3	0. 4	0. 164	59. 92	15, 303	
		1	4	0. 4	0. 220	94. 20	20, 690	
		1	5	0. 4	0. 187	72. 63	17, 398	
		1	6	0. 4	0. 190	74. 30	17, 665	
		3	7	0. 3	0. 197	2. 98	2, 071	
526	Explosive, gun-cotton, wet; ring, 4 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 75 feet; case, can No. 2, no tamping; ignition, Farmer dynamo, 1 Abel fuze, and 1 pound of dry gun-cotton. Effects: Same remarks as for shot No. 525. Two Abel fuzes failed in succession to explode.	1	1	0. 4	0. 183	70. 38	17, 035	
		1	2	0. 4	0. 195	77. 22	18, 120	
		1	3	0. 4	0. 178	67. 52	16, 570	Stuck by gas-check; rounded.
		1	4	0. 4	0. 217	92. 01	20, 366	
		1	5	0. 4	0. 178	67. 52	16, 570	
		1	6	0. 4	0. 199	79. 81	18, 524	
		3	7	0. 3	0. 175	2. 50	1, 841	
527	Explosive, gun-cotton, wet; ring, 4 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 75 feet; case, can No. 2, no tamping; ignition, Farmer dynamo, 1 Abel fuze, and 1 pound of dry gun-cotton. Effects: Same remarks as for shot No. 525. Three Abel fuzes failed to explode in succession; shall condemn them hereafter. Bale of wire rope broken.	1	1	0. 4	0. 204	83. 16	19, 041	
		1	2	0. 4	0. 154	.....	......	Pin badly jammed.
		1	3	0. 4	0. 203	82. 48	18, 937	
		1	4	0. 4	0. 213	89. 13	19, 938	
		1	5	0. 4	0. 074	.....	......	Bad catch (?).
		1	6	0. 4	0. 189	73. 74	17, 576	
		3	7	0. 3	0. 151	2. 00	1, 587	
528	Explosive, gun-cotton, wet; ring, 4 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 75 feet; case, can No. 2, no tamping; ignition, Farmer dynamo, 1 service low tension fuze, and 1 pound dry gun-cotton. Effects: Same remarks as for shot No. 525. Normal.	1	1	0. 4	0. 201	81. 13	18, 729	Gauge head broken.
		1	2	0. 4	0. 160	57. 90	14, 957	
		1	3	0. 4	0. 210	87. 00	19, 620	
		1	4	0. 4	0. 182	69. 81	16, 942	
		1	5	0. 4	0. 156	55. 70	14, 575	
		1	6	0. 4	0. 172	64. 18	16, 018	
		3	7	0. 3	0. 213	3. 36	2, 242	
529	Explosive, gun-cotton, wet; ring, 4 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 75 feet; case, can No. 2, no tamping; ignition, Farmer dynamo, 1 service low tension fuze, and 1 pound dry gun-cotton. Effects: Same remarks as for shot No. 525. Suspension strap broke, but did not allow ring to escape.	1	1	0. 4	0. 209	86. 37	19, 525	
		1	2	0. 4	0. 196	77. 87	18, 221	
		1	3	0. 4	0. 243	111. 10	23, 007	
		1	4	0. 4	0. 209	86. 37	19, 525	
		1	5	0. 4	0. 170	63. 10	15, 837	
		1	6	0. 4	0. 151	53. 14	14, 128	
		3	7	0. 3	0. 131	1. 62	1, 377	
530	Explosive, gun-cotton, wet; ring, 4 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 75 feet; case, can No. 2, no tamping; ignition, Farmer dynamo, 1 service low tension fuze, and 1 pound of dry gun-cotton. Effects: Same remarks as for shot No. 525. Lowering rope parted, and had to raise ring by wire suspension rope.	1	1	0. 4	0. 206	84. 47	19, 240	
		1	2	0. 4	0. 184	70. 95	17, 127	
		1	3	0. 4	0. 229	100. 67	21, 626	
		1	4	0. 4	0. 221	94. 91	20, 794	
		1	5	0. 4	0. 167	61. 50	15, 569	
		1	6	0. 4	0. 180	68. 67	16, 757	Broke head.
		3	7	0. 3	0. 170	2. 41	1, 796	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
531	Explosive, gun-cotton, wet; ring, 4 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 75 feet; case, can No. 2, no tamping; ignition, Farmer dynamo, 1 service low tension fuse, and 1 pound of dry gun-cotton. Effects: Same remarks as for shot No. 525.	1	1	0. 4	0. 204	83. 16	19, 041	
		1	2	0. 4	0. 181	69. 24	16, 850	
		1	3	0. 4	0. 239	108. 10	22, 675	
		1	4	0. 4	0. 204	83. 16	19, 041	
		1	5	0. 4	0. 188	73, 19	17, 487	
		1	6	0. 4	0. 175	65. 80	16, 290	
		3	7	0. 3	0. 158	2. 16	1, 667	
532	Explosive, gun-cotton, wet; ring, 4 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 75 feet; case, can No. 2, no tamping; ignition, Farmer dynamo, 1 service low tension fuze, and 1 pound of dry gun-cotton. Effects: Same remarks as for shot No. 525.	1	1	0. 4	0. 209	86. 37	19, 525	
		1	2	0. 4	0. 195	77. 22	18, 120	
		1	3	0. 4	0. 231	102. 10	21, 835	
		1	4	0. 4	0. 207	85. 10	19, 335	
		1	5	0. 4	0. 189	73. 74	17, 576	
		1	6	0. 4	0. 192	75. 47	17, 847	
		3	7	0. 3	0. 195	2. 94	2, 050	
533	Explosive, gun-cotton; ring, 4 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 75 feet; case, can No. 2, no tamping; ignition, Farmer dynamo, 1 service low tension fuze, and 1 pound of dry gun-cotton. Effects: Same remarks as for shot No. 525. Bolt of shackle slipped and let down ring.	1	1	0. 4	0. 240	108. 80	22, 780	
		1	2	0. 4	0. 209	86. 37	19, 525	
		1	3	0. 4	0. 224	97. 04	21, 106	
		1	4	0. 4	0. 181	69. 24	16, 850	
		1	5	0. 4	0. 175	65. 80	16, 383	
		1	6	0. 4	0. 154	54. 65	14, 392	
		3	7	0. 3	0. 243	4. 21	2, 604	
534	Explosive, gun-cotton, wet; ring, 4 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 75 feet; case, can No. 2, no tamping; ignition, Farmer dynamo, 1 service low tension fuze, and 1 pound of dry gun-cotton. Effects: Same remarks as for shot No. 525. Broke lowering ring and parted rope, letting ring down.	1	1	0. 4	0. 213	89. 13	19, 938	
		1	2	0. 4	0. 223	96. 33	21, 002	
		1	3	0. 4	0. 224	97. 04	21, 106	
		1	4	0. 4	0. 207	85. 10	19, 335	
		1	5	0. 4	0. 178	67. 52	16, 570	
		1	6	0. 4	0. 169	62. 57	15, 748	
		3	7	0. 3	0. 199	3. 01	2, 092	
535	Explosive, gun-cotton, dry; ring, 4 foot; charge, 5 pounds, submergence, 34 feet; depth of water, 65 feet; case, can No. 2, no tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: A 5-foot boil, as usual.	1	1	0. 4	0. 198	79. 16	18, 423	
		1	2	0. 4	0. 226	98. 48	21, 314	
		1	3	0. 4	0. 219	93. 47	20, 582	
		1	4	0. 4	0. 246	113. 50	23, 428	
		1	5	0. 4	0. 177	66. 95	16, 477	
		1	6	0. 4	0. 188	73. 19	17, 487	
		3	7	0. 3	0. 126	1. 53	1, 326	
536	Explosive, gun-cotton, dry; ring, 4 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 65 feet; case, can No. 2, no tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0. 4	0. 197	78. 52	18, 322	
		1	2	0. 4	0. 206	84. 47	19, 240	
		1	3	0. 4	0. 215	90. 55	20, 150	
		1	4	0. 4	0. 204	83. 16	19, 041	
		1	5	0. 4	0. 188	73. 19	17, 487	
		1	6	0. 4	0. 195	77. 22	18, 120	
		3	7	0. 3	0. 161	2. 22	1, 699	
537	Explosive, gun-cotton, dry; ring, 4 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 65 feet; case, can No. 2, no tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0. 4	0. 226	98. 48	21, 314	
		1	2	0. 4	0. 214	89. 84	20, 044	
		1	3	0. 4	0. 230	101. 40	21, 730	
		1	4	0. 4	0. 198	79. 16	18, 423	
		1	5	0. 4	0. 199	79. 81	18, 524	
		1	6	0. 4	0. 193	76. 05	17, 938	
		3	7	0. 3	0. 110	1. 27	1, 172	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
538	Explosive, gun-cotton; ring, 4 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 65 feet; case, can No. 2, no tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.205	83.84	19,145	
		1	2	0.4	0.201	81.13	18,729	
		1	3	0.4	0.194	76.64	18,029	
		1	4	0.4	0.160	57.90	14,957	
		1	5	0.4	0.169	62.57	15,748	
		1	6	0.4	0.196	77.87	18,221	
		3	7	0.3	0.104	1.17	1,112	
539	Explosive, gun-cotton; ring, 4 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 65 feet; case, can No. 2, no tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal. Last shot of season, fired on October 29, 1878.	1	1	0.4	0.197	78.52	18,322	
		1	2	0.4	0.205	83.84	19,145	
		1	3	0.4	0.240	108.80	22,780	
		1	4	0.4	0.217	92.01	20,366	
		1	5	0.4	0.171	63.64	15,928	
		1	6	0.4	0.179	68.10	16,664	
		3	7	0.3	0.131	1.62	1,377	
540	Explosive, Hercules No. 2; ring, 4 foot; charge, 1 pound; submergence, 33 feet; depth of water, 80 feet; case, fuze can; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 1 foot, and several seconds afterward an upward boiling of water occurred. First shot of season fired May 15, 1879.	1	1	0.4	0.086	24.07	8,330	
		1	2	0.4	0.167	.....	......	Gauge defective.
		1	3	0.4	0.072	19.08	7,135	
		1	4	0.4	0.088	24.82	8,502	
		1	5	0.4	0.055	13.50	5,666	
		1	6	0.4	0.056	13.83	5,757	
		3	7	0.3	0.032	0.24	389	
541	Explosive, Hercules No. 2; ring, 4 foot; charge, 1 pound, submergence, 33 feet; depth of water, 80 feet; case, fuze can; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.089	25.19	8,588	
		1	2	0.4	0.149	.....	......	Top of gauge broke.
		1	3	0.4	0.071	18.75	7,053	
		1	4	0.4	0.092	26.32	8,841	
		1	5	0.4	0.067	17.41	6,711	
		1	6	0.4	0.056	13.83	5,757	
		3	7	0.3	0.042	0.36	502	
542	Explosive, Hercules No. 2; ring. 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 3 feet; subsided, and a boil rose after several seconds.	1	1	0.4	0.191	74.88	17,756	
		1	2	0.4	0.163	59.42	15,217	
		1	3	0.4	0.113	34.94	10,679	
		1	4	0.4	0.114	35.38	10,768	
		1	5	0.4	0.106	32.02	10,076	
		1	6	0.4	0.121	38.52	11,398	
		3	7	0.3	0.079	0.81	866	
543	Explosive, Hercules No. 2; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.159	57.35	14,862	
		1	2	0.4	0.156	55.70	14,575	
		1	3	0.4	0.099	29.13	9,460	
		1	4	0.4	0.120	38.05	11,305	
		1	5	0.4	0.097	28.28	9,276	
		1	6	0.4	0.103	30.85	9,816	
		3	7	0.3	0.088	0.95	964	
544	Explosive, Hercules No. 2; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 1, full; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy shot up 4 feet and sunk out of sight; a small boil rose with it.	1	1	0.4	0.164	59.92	15,303	
		1	2	0.4	0.143	49.06	13,397	
		1	3	0.4	0.138	46.59	12,939	
		1	4	0.4	0.142	48.56	13,303	
		1	5	0.4	0.132	43.62	12,381	
		1	6	0.4	0.112	34.50	10,590	
		3	7	0.3	0.128	1.56	1,347	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
545	Explosive, Hercules No. 2; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 1, full; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.132	43.62	12,381	
		1	2	0.4	0.152	53.64	14,216	
		1	3	0.4	0.135	45.20	12,677	
		1	4	0.4	0.150	52.64	14,040	
		1	5	0.4	0.099	29.13	9,460	
		1	6	0.4	0.118	37.16	11,126	
		3	7	0.3	0.125	1.51	1,316	
546	Explosive, Hercules No. 2; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy shot up 4 feet and sunk before a 3-foot dome rose to surface.	1	1	0.4	0.185	71.52	17,220	
		1	2	0.4	0.175	65.80	16,290	
		1	3	0.4	0.143	49.08	13,397	
		1	4	0.4	0.160	57.90	14,957	
		1	5	0.4	0.099	29.13	9,460	
		1	6	0.4	0.137	46.13	12,851	
		3	7	0.3	0.161	2.22	1,099	
547	Explosive, Hercules No. 2; ring 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.181	69.24	16,850	
		1	2	0.4	0.173	64.72	16,109	
		1	3	0.4	0.164	59.92	15,303	
		1	4	0.4	0.168	62.03	15,658	
		1	5	0.4	0.114	35.38	10,768	
		1	6	0.4	0.136	45.66	12,764	
		3	7	0.3	0.168	2.36	1,772	
548	Explosive, Hercules No. 2; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuse. Effects: Buoy rose 5 feet and fell over.	1	1	0.4	0.194	76.64	18,029	
		1	2	0.4	0.192	75.47	17,847	
		1	3	0.4	0.188	73.19	17,487	
		1	4	0.4	0.225	97.75	21,210	
		1	5	0.4	0.147	50.78	13,768	
		1	6	0.4	0.150	52.64	14,040	
		3	7	0.3	0.187	2.78	1,977	
549	Explosive, Hercules No. 2; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuse. Effects: Normal.	1	1	0.4	0.208	85.74	19,430	Broke socket.
		1	2	0.4	0.202	81.81	18,833	Broke pin.
		1	3	0.4	0.204	83.16	19,041	
		1	4	0.4	0.202	81.81	18,833	
		1	5	0.4	0.155	55.15	14,480	
		1	6	0.4	0.167	61.50	15,569	
		3	7	0.3	0.265	4.88	2,875	
550	Explosive, Hercules No. 1; ring, 4 foot; charge, 1 pound; submergence, 33 feet; depth of water, 79 feet; case, fuze can; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 1 foot and sunk before boil rose.	1	1	0.4	0.152	53.64	14,216	Hammered lead.
		1	2	0.4	0.152	53.64	14,216	Hammered lead; gauge broken.
		1	3	0.4	0.112	34.50	10,580	
		1	4	0.4	0.098	28.71	9,368	
		1	5	0.4	0.086	24.07	8,330	
		1	6	0.4	0.093	26.69	8,925	
		3	7	0.3	0.051	0.45	588	
551	Explosive, Hercules No. 1; ring, 4 foot; charge 1 pound; submergence, 33 feet; depth of water, 79 feet; case, fuze can; ignition, Laflin & Rand dynamo, 1 service low tension fuse. Effects: Normal.	1	1	0.4	0.139	47.06	13,026	Hammered lead.
		1	2	0.4	0.159	57.35	14,862	
		1	3	0.4	0.094	27.07	9,009	
		1	4	0.4	0.094	27.07	9,009	
		1	5	0.4	0.078	21.21	7,654	
		1	6	0.4	0.083	23.00	8,060	
		3	7	0.3	0.049	0.43	567	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
552	Explosive, Hercules No. 1; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 2 or 3 feet; boil long after its sinking and reappearance.	1	1	0.4	0.187	72.63	17,398	
		1	2	0.4	0.161	58.41	15,044	
		1	3	0.4	0.154	54.65	14,392	
		1	4	0.4	0.155	55.15	14,480	
		1	5	0.4	0.126	40.85	11,853	
		1	6	0.4	0.141	48.04	13,208	
		3	7	0.3	0.174	2.48	1,832	
553	Explosive, Hercules No. 1; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Lowering rope parted at ring; the boil rose like a balloon through the water several seconds after buoy reappeared.	1	1	0.4	0.140	47.52	13,113	
		1	2	0.4	0.147	50.73	13,768	
		1	3	0.4	0.149	51.34	13,949	
		1	4	0.4	0.154	54.65	14,392	
		1	5	0.4	0.120	38.05	11,305	
		1	6	0.4	0.132	43.62	12,381	
		3	7	0.3	0.139	1.75	1,453	
554	Explosive, Hercules No. 1; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 79 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.186	72.08	17,309	
		1	2	0.4	0.169	62.57	15,748	
		1	3	0.4	0.200	80.46	18,625	
		1	4	0.4	0.193	76.05	17,938	
		1	5	0.4	0.171	63.64	15,928	
		1	6	0.4	0.177	66.95	16,477	
		3	7	0.3	0.189	2.82	1,998	
555	Explosive, Hercules No. 1; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 73 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Lowering rope parted at ring; wire mooring rope bale broke; as the ring was raising by guard rope, the latter parted; thus the ring was lost.	1	1	0.4	.....	......	......	Lost ring.
		1	2	0.4	.....	......	......	
		1	3	0.4	.....	......	......	
		1	4	0.4	.....	......	......	
		1	5	0.4	.....	......	......	
		1	6	0.4	.....	......	......	
		3	7	0.3	0.177	2.54	1,859	
556	Explosive, Hercules No. 1; ring, 5 foot; charge, 4 pounds; submergence, 34 feet; depth of water, 73 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.165	60.43	15,390	
		1	2	0.4	0.176	66 37	16,383	
		1	3	0.4	0.140	47.52	13,113	
		1	4	0.4	0.139	47.06	13,026	
		1	5	0.4	0.141	48.04	13,208	
		1	6	0.4	0.131	43.09	12,282	
		3	7	0.3	0.222	3.60	2,348	
557	Explosive, Hercules No. 1; ring, 5 foot; charge, 4 pounds; submergence, 34 feet; depth of water, 73 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Gib and key fell out, causing loss of No. 2 socket and gauge.	1	1	0.4	0.187	72.63	17,398	
		1	2	0.4	.....	......	......	Lost gauge and socket.
		1	3	0.4	0.163	59.42	15,217	
		1	4	0.4	0.157	56.25	14,671	
		1	5	0.4	0.139	47.06	13,026	
		1	6	0.4	0.121	38.52	11,308	
		3	7	0.3	0.140	1.77	1,402	
558	Explosive, Hercules No. 1; ring, 5 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 73 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Broke suspension strap, but it did not let ring escape.	1	1	0.4	0.185	71.52	17,220	
		1	2	0.4	0.191	74.88	17,756	
		1	3	0.4	0.169	62.57	15,748	
		1	4	0.4	0.156	55.70	14,575	
		1	5	0.4	0.156	55.70	14,575	
		1	6	0.4	0.171	63.64	15,928	
		3	7	0.3	0.236	3.99	2,514	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
559	Explosive, Hercules No. 1; ring, 5 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 73 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.187	72.63	17,398	
		1	2	0.4	0.210	87.00	19,620	
		1	3	0.4	0.161	58.41	15,044	
		1	4	0.4	0.150	52.64	14,040	
		1	5	0.4	0.165	60.43	15,390	
		1	6	0.4	0.157	56.25	14,671	
		3	7	0.3	0.270	5.03	2,934	
560	Explosive, Hercules No. 2; ring, 5 foot; charge, 4 pounds; submergence, 34 feet; depth of water, 80 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 3½ feet and sunk in a jet about 3 feet high.	1	1	0.4	0.136	45.66	12,764	
		1	2	0.4	0.136	45.66	12,764	
		1	3	0.4	0.093	26.69	8,925	
		1	4	0.4	0.123	39.47	11,584	
		1	5	0.4	0.084	23.34	8,162	
		1	6	0.4	0.091	25.94	8,758	
		3	7	0.3	0.138	1.74	1,444	
561	Explosive, Hercules No. 2; ring, 5 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 80 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Jet about 3 feet high.	1	1	0.4	0.143	49.08	13,397	
		1	2	0.4	0.126	40.85	11,853	
		1	3	0.4	0.113	34.94	10,679	
		1	4	0.4	0.138	46.59	12,939	Gauge broke.
		1	5	0.4	0.109	33.22	10,328	
		1	6	0.4	0.124	39.95	11,677	
		3	7	0.3	0.241	4.14	2,577	
562	Explosive, Hercules No. 2; ring, 5 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 80 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 4½ feet and sunk into a 3-foot dome.	1	1	0.4	0.144	49.60	13,492	
		1	2	0.4	0.134	44.67	12,578	
		1	3	0.4	0.106	32.02	10,076	
		1	4	0.4	0.140	47.52	13,113	
		1	5	0.4	0.111	34.06	10,501	
		1	6	0.4	0.082	22.65	7,999	
		3	7	0.3	0.197	2.98	2,071	
563	Explosive, Hercules No. 2; ring, 5 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 80 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 5 feet.	1	1	0.4	0.136	45.66	12,764	
		1	2	0.4	0 158	56.80	14,766	
		1	3	0.4	0.111	34.06	10,501	
		1	4	0.4	0.128	41.70	12,018	
		1	5	0.4	0.095	27.44	9,092	
		1	6	0.4	0.133	44.14	12,479	
		3	7	0.3	0.174	2.48	1,832	
564	Explosive, Hercules No. 1; ring, 5 foot; charge, 4 pounds, submergence, 34 feet; depth of water, 80 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.174	65.36	16,199	Elongated mark.
		1	2	0.4	0.143	49.08	13,397	
		1	3	0.4	0.128	41.70	12,018	
		1	4	0.4	0.129	42.13	12,100	
		1	5	0.4	0.111	34.06	10,501	
		1	6	0.4	0.141	48.04	13,208	
		3	7	0.3	0.229	3.79	2,427	
565	Explosive, Hercules No. 1; ring, 5 foot; charge, 5 pounds; submergence. 34 feet; depth of water, 80 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 5 feet and fell in a 6-foot dome.	1	1	0.4	0.174	65.36	16,199	
		1	2	0.4	0.174	65.36	16,199	
		1	3	0.4	0.160	57.90	14,957	
		1	4	0.4	0.157	56.25	14,671	
		1	5	0.4	0.153	54.15	14,304	Gauge broken.
		1	6	0.4	0.149	51.34	13,949	
		3	7	0.3	0.228	3.77	2,418	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
566	Explosive, Hercules No. 1; ring, 5 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 80 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.138	......	......	Pin jammed.
		1	2	0.4	0.167	61.50	15,569	
		1	3	0.4	0.177	66.95	16,477	
		1	4	0.4	0.151	53.14	14,128	
		1	5	0.4	0.158	56.80	14,766	
		1	6	0.4	0.165	60.43	15,300	
		3	7	0.3	0.316	6.58	3,477	
567	Explosive, Hercules No. 1; ring, 5 foot; charge, 5 pounds; submergence, 34 feet; depth of water, 80 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.187	72.63	17,398	Broke pin.
		1	2	0.4	0.172	64.18	16,018	
		1	3	0.4	0.146	50.42	13,678	
		1	4	0.4	0.152	53.64	14,216	
		1	5	0.4	0.151	53.14	14,128	
		1	6	0.4	0.153	54.15	14,304	
		3	7	0.3	0.225	3.70	2,390	
568 to 615	Fired from slab to study sympathetic explosions.—See page 125.							
616	Explosive, electric powder No. 1; ring, 4 foot; charge, 1 pound; submergence, 33 feet; depth of water, 82 feet; case, fuze can; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose slightly.	1	1	0.4	0.069	18.08	6,884	
		1	2	0.4	0.050	12.03	5,215	
		1	3	0.4	0.065	16.73	6,537	
		1	4	0.4	0.052	12.62	5,395	
		1	5	0.4	0.054	13.21	5,576	
		1	6	0.4	0.046	10.76	4,864	
		3	7	0.3	0.015	0.09	201	
617	Explosive, electric powder No. 1; ring, 4 foot; charge, 1 pound; submergence, 33 feet; depth of water, 82 feet; case, fuze can; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 6 inches; the bubbles were unusually slow in appearing.	1	1	0.4	0.053	12.91	5,486	
		1	2	0.4	0.052	12.62	5,395	
		1	3	0.4	0.062	15.78	6,286	
		1	4	0.4	0.068	17.74	6,797	
		1	5	0.4	0.052	12.62	5,395	
		1	6	0.4	0.056	13.83	5,757	
		3	7	0.3	0.016	0.10	209	
618	Explosive, electric powder No. 1; ring, 4 foot; charge, 1 pound; submergence, 33 feet; depth of water, 82 feet; case, fuze can; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.122	......	......	Defective gauge.
		1	2	0.4	0.032	12.62	5,395	
		1	3	0.4	0.077	20.83	7,564	
		1	4	0.4	0.055	13.50	5,666	
		1	5	0.4	0.056	13.83	5,757	
		1	6	0.4	0.052	12.62	5,395	
		3	7	0.3	0.014	0.09	191	
619	Explosive, electric powder No. 2; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.083	23.00	8,080	
		1	2	0.4	0.079	21.58	7,745	
		1	3	0.4	0.093	26.69	8,925	
		1	4	0.4	0.075	20.08	7,382	
		1	5	0.4	0,092	26 32	8,841	
		1	6	0.4	0.084	23.34	8,162	
		3	7	0.3	0.031	0.23	377	
620	Explosive, electric powder No. 2; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 1 foot.	1	1	0.4	0.067	17.41	6,711	
		1	2	0.4	0.079	21.58	7,745	
		1	3	0.4	0.071	18.75	7,053	
		1	4	0.4	0.068	17.74	6,797	
		1	5	0.4	0.053	12.91	5,486	
		1	6	0.4	0.059	14.82	6,028	
		3	7	0.3	0.020	0.12	243	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
621	Explosive, electric powder No. 2; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.076	20.46	7,473	
		1	2	0.4	0.057	14.16	5,847	
		1	3	0.4	0.053	13.50	5,666	
		1	4	0.4	0.060	15.15	6,119	
		1	5	0.4	0.065	16.73	6,537	
		1	6	0.4	0.057	14.16	5,847	
		3	7	0.3	0.020	0.12	243	
622	Explosive, electric powder No. 2; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 1; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 2½ feet.	1	1	0.4	0.121	38.52	11,398	
		1	2	0.4	0.100	29.55	9,552	
		1	3	0.4	0.139	47.06	13,026	
		1	4	0.4	0.127	41.28	11,935	
		1	5	0.4	0.121	38.52	11,398	
		1	6	0.4	0.090	25.57	8,674	
		3	7	0.3	0.078	0.79	856	
623	Explosive, electric powder No. 2; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 1; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 3½ feet.	1	1	0.4	0.106	32.02	10,076	
		1	2	0.4	0.094	27.07	9,009	
		1	3	0.4	0.125	40.42	11,770	
		1	4	0.4	0.120	38.05	11,305	
		1	5	0.4	0.119	37.60	11,215	
		1	6	0.4	0.111	34.06	10,501	
		3	7	0.3	0.079	0.81	866	
624	Explosive, electric powder No. 2; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 1; ignition, Laflin & Rand dynamo, 1 service, low tension fuze. Effects: Buoy rose 3 feet.	1	1	0.4	0.092	26.32	8,841	
		1	2	0.4	0.088	24.82	8,502	
		1	3	0.4	0.109	33.22	10,328	
		1	4	0.4	0.097	28.28	9,276	
		1	5	0.4	0.121	38.52	11,398	
		1	6	0.4	0.104	31.29	9,904	
		3	7	0.3	0.073	0.73	810	
625	Explosive, electric powder, No. 2; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 4 feet; dome appeared after it had sunk out of sight.	1	1	0.4	0.129	42.13	12,100	
		1	2	0.4	0.111	34.06	10,501	
		1	3	0.4	0.129	42.13	12,100	
		1	4	0.4	0.116	36.27	10,947	
		1	5	0.4	0.115	35.82	10,857	
		1	6	0.4	0.106	32.02	10,076	
		3	7	0.3	0.140	1.77	1,462	
626	Explosive, electric powder No. 2; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 3 feet.	1	1	0.4	0.128	41.70	12,018	
		1	2	0.4	0.122	39.00	11,491	
		1	3	0.4	0.113	34.94	10,679	
		1	4	0.4	0.121	38.52	11,398	
		1	5	0.4	0.129	42.13	12,100	
		1	6	0.4	0.109	33.22	10,328	
		3	7	0.3	0.100	1.11	1,071	
627	Explosive, electric powder No. 2; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 3 feet; sunk, and a 2-foot boil rose at once over it.	1	1	0.4	0.132	43.63	12,381	
		1	2	0.4	0.123	39.47	11,584	
		1	3	0.4	0.113	34.94	10,679	
		1	4	0.4	0.119	37.60	11,215	
		1	5	0.4	0.116	36.27	10,947	
		1	6	0.4	0.101	29.98	9,640	
		3	7	0.3	0.108	1.24	1,152	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
628	Explosive, electric powder No. 2; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 4 feet.	1	1	0.4	0.152	53.64	14,216	
		1	2	0.4	0.140	47.52	13,113	
		1	3	0.4	0.161	58.41	15,044	
		1	4	0.4	0.147	50.73	13,768	
		1	5	0.4	0.159	57.35	14,862	
		1	6	0.4	0.120	38.05	11,305	
		3	7	0.3	0.123	1.48	1,297	
629	Explosive, electric powder No. 2; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 4 feet; boil, 3 feet.	1	1	0.4	0.140	47.52	13,113	
		1	2	0.4	0.131	43.09	12,282	
		1	3	0.4	0.155	55.15	14,480	
		1	4	0.4	0.131	43.09	12,282	
		1	5	0.4	0.143	49.08	13,397	
		1	6	0.4	0.126	40.85	11,853	
		3	7	0.3	0.111	1.28	1,181	
630	Explosive, electric powder No. 2; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose less than before.	1	1	0.4	0.137	46.13	12,851	
		1	2	0.4	0.142	48.56	13,303	
		1	3	0.4	0.153	54.15	14,304	
		1	4	0.4	0.147	50.73	13,768	
		1	5	0.4	0.149	51.34	13,949	
		1	6	0.4	0.133	44.14	12,479	
		3	7	0.3	0.177	2.54	1,859	
631	Explosive, electric powder No. 1; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 2 feet.	1	1	0.4	0.077	20.83	7,564	
		1	2	0.4	0.067	17.41	6,711	
		1	3	0.4	0.077	20.83	7,564	
		1	4	0.4	0.077	20.83	7,564	
		1	5	0.4	0.075	20.08	7,382	
		1	6	0.4	0.085	23.69	8,244	
		3	7	0.3	0.032	0.24	389	
632	Explosive, electric powder No. 1; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 2½ feet; large upward boiling of water.	1	1	0.4	0.096	27.86	9,184	
		1	2	0.4	0.078	21.21	7,654	
		1	3	0.4	0.083	23.00	8,080	
		1	4	0.4	0.077	20.83	7,564	
		1	5	0.4	0.077	20.83	7,564	
		1	6	0.4	0.082	22.65	7,999	
		3	7	0.3	0.051	0.45	588	
633	Explosive, electric powder No. 1; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.065	16.73	6,537	
		1	2	0.4	0.065	16.73	6,537	
		1	3	0.4	0.072	19.08	7,135	
		1	4	0.4	0.069	18.08	6,884	
		1	5	0.4	0.065	16.73	6,537	
		1	6	0.4	0.064	16.42	6,453	
		3	7	0.3	0.031	0.23	377	
634	Explosive, electric powder No. 1; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 1; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 4½ feet.	1	1	0.4	0.116	36.27	10,947	
		1	2	0.4	0.109	33.22	10,328	
		1	3	0.4	0.132	43.62	12,381	
		1	4	0.4	0.123	39.47	11,584	
		1	5	0.4	0.116	36.27	10,947	
		1	6	0.4	0.104	31.29	9,904	
		3	7	0.3	0.100	1.11	1,071	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
635	Explosive, electric powder No. 1; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 1; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 4½ feet; boil 1 foot high.	1	1	0.4	0.120	38.05	11,305	
		1	2	0.4	0.125	40.42	11,770	
		1	3	0.4	0.125	40.42	11,770	
		1	4	0.4	0.122	39.00	11,491	
		1	5	0.4	0.109	33.22	10,328	
		1	6	0.4	0.118	37.16	11,126	
		3	7	0.3	0.080	0.82	876	
636	Explosive, electric powder No. 1; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 1; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.120	38.05	11,305	
		1	2	0.4	0.117	36.71	11,036	
		1	3	0.4	0.130	42.56	12,183	
		1	4	0.4	0.115	35.82	10,857	
		1	5	0.4	0.126	40.85	11,853	
		1	6	0.4	0.119	37.60	11,215	
		3	7	0.3	0.098	1.08	1,053	
637	Explosive, electric powder No. 1; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 4½ feet.	1	1	0.4	0.141	48.04	13,208	
		1	2	0.4	0.135	45.20	12,677	
		1	3	0.4	0.123	39.47	11,584	
		1	4	0.4	0.139	47.06	13,026	
		1	5	0.4	0.136	45.66	12,764	
		1	6	0.4	0.116	36.27	10,947	
		3	7	0.3	0.127	1.55	1,336	
638	Explosive, electric powder No. 1; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose only 2 feet, and boiling of water was less than for last shot.	1	1	0.4	0.096	27.86	9,184	
		1	2	0.4	0.085	23.69	8,244	
		1	3	0.4	0.079	21.58	7,745	
		1	4	0.4	0.079	21.58	7,745	
		1	5	0.4	0.076	20.46	7,473	
		1	6	0.4	0.067	17.41	6,711	
		3	7	0.3	0.037	0.30	451	
639	Explosive, electric powder No. 1; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 3½ feet; dome about 1½ feet high.	1	1	0.4	0.132	43.62	12,381	
		1	2	0.4	0.123	39.47	11,584	
		1	3	0.4	0.137	46.13	12,851	
		1	4	0.4	0.135	45.20	12,677	
		1	5	0.4	0.125	40.42	11,770	
		1	6	0.4	0.119	37.60	11,215	
		3	7	0.3	0.119	1.41	1,258	
640	Explosive, electric powder No. 1; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 4½ feet; a 2-foot dome of water.	1	1	0.4	0.174	65.26	16,199	
		1	2	0.4	0.156	55.70	14,575	
		1	3	0.4	0.161	58.41	15,044	
		1	4	0.4	0.157	56.25	14,671	
		1	5	0.4	0.158	56.80	14,766	
		1	6	0.4	0.153	54.15	14,304	
		3	7	0.3	0.088	0.95	964	
641	Explosive, electric powder No. 1; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 82 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy and dome as in last shot; officers at distance of a mile report fish as jumping from water near them at explosion.	1	1	0.4	0.162	58.91	15,130	
		1	2	0.4	0.147	50.73	13,768	
		1	3	0.4	0.136	45.66	12,764	
		1	4	0.4	0.145	50.12	13,587	
		1	5	0.4	0.157	56.25	14,671	
		1	6	0.4	0.136	45.66	12,764	
		3	7	0.3	......	......	......	Slipped.

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
642	Explosive, picric powder; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 2½ feet.	1	1	0.4	0.116	36.27	10,947	
		1	2	0.4	0.138	46.59	12,939	
		1	3	0.4	0.116	36.27	10,947	
		1	4	0.4	0.113	34.94	10,679	
		1	5	0.4	0.104	31.29	9,904	
		1	6	0.4	0.094	27.07	9,009	
		3	7	0.3	0.124	1.49	1,306	
643	Explosive, picric powder; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 2½ feet.	1	1	0.4	0.117	36.71	11,036	
		1	2	0.4	0.147	50.73	13,768	
		1	3	0.4	0.104	31.29	9,904	
		1	4	0.4	0.108	32.82	10,244	
		1	5	0.4	0.107	32.42	10,160	
		1	6	0.4	0.103	30.85	9,816	
		3	7	0.3	0.090	0.98	986	
644	Explosive, picric powder; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo. 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.112	34.50	10,590	
		1	2	0.4	0.120	38.05	11,305	
		1	3	0.4	0.097	28.28	9,276	
		1	4	0.4	0.107	32.42	10,160	
		1	5	0.4	0.097	28.28	9,276	
		1	6	0.4	0.100	29.55	9,552	
		3	7	0.3	0.094	1.03	1,018	
645	Explosive, picric powder; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 1; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 3½ feet.	1	1	0.4	0.128	41.70	12,018	
		1	2	0.4	0.127	41.28	11,935	
		1	3	0.4	0.148	51.03	13,859	
		1	4	0.4	0.149	51.34	13,949	
		1	5	0.4	0.136	45.66	12,764	
		1	6	0.4	0.137	46.13	12,851	
		3	7	0.3	0.080	0.82	876	
646	Explosive, picric powder; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 1; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 4½ feet.	1	1	0.4	0.137	46.13	12,851	
		1	2	0.4	0.138	46.59	12,939	
		1	3	0.4	0.138	46.59	12,939	
		1	4	0.4	0.145	50.12	13,587	
		1	5	0.4	0.138	46.59	12,939	
		1	6	0.4	0.136	45.66	12,764	
		3	7	0.3	0.163	2.25	1,718	
647	Explosive, picric powder; ring, 4 feet; charge, 3 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 1; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Like last shot.	1	1	0.4	0.141	48.04	13,208	
		1	2	0.4	0.136	45.66	12,764	
		1	3	0.4	0.151	53.14	14,128	
		1	4	0.4	0.141	48.04	13,208	
		1	5	0.4	0.150	52.64	14,040	
		1	6	0.4	0.141	48.04	13,208	
		3	7	0.3	0.145	1.87	1,517	
648	Explosive, picric powder; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 5½ feet; dome 2 feet high.	1	1	0.4	0.164	59.92	15,303	
		1	2	0.4	0.168	62.03	15,658	
		1	3	0.4	0.154	54.65	14,392	
		1	4	0.4	0.150	52.64	14,040	
		1	5	0.4	0.162	58.91	15,130	
		1	6	0.4	0.139	47.06	13,026	
		3	7	0.3	0.204	3.15	2,146	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
649	Explosive, picric powder; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.162	58.91	15,130	
		1	2	0.4	0.137	46.13	12,851	
		1	3	0.4	0.157	56.25	14,671	
		1	4	0.4	0.167	61.50	15,569	
		1	5	0.4	0.159	57.35	14,862	
		1	6	0.4	0.156	55.70	14,575	
		3	7	0.3	0.162	2.24	1,708	
650	Explosive, picric powder; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Strong squall of wind. Effects: buoy rose only 2 feet, but boil was normal; Private Kirwin had finger caught in block in raising ring; the first accident during these trials.	1	1	0.4	0.152	53.64	14,216	
		1	2	0.4	0.150	52.64	14,040	
		1	3	0.4	0.137	46.13	12,851	
		1	4	0.4	0.163	59.42	15,217	
		1	5	0.4	0.144	49.60	13,492	
		1	6	0.4	0.156	55.70	14,575	
		3	7	0.3	0.159	2.18	1,679	
651	Explosive, Designolle powder; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 2½ feet; used a third boat for carrying the loaded torpedoes for first time.	1	1	0.4	0.111	34.66	10,501	
		1	2	0.4	0.122	39.00	11,491	
		1	3	0.4	0.069	18.08	6,884	
		1	4	0.4	0.099	29.13	9,460	
		1	5	0.4	0.071	18.75	7,053	
		1	6	0.4	0.075	20.08	7,382	
		3	7	0.3	0.039	0.33	475	
652	Explosive, Designolle powder; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.099	29.13	9,460	
		1	2	0.4	0.100	29.55	9,552	
		1	3	0.4	0.086	24.07	8,330	
		1	4	0.4	0.091	25.94	8,758	
		1	5	0.4	0.064	16.42	6,453	
		1	6	0.4	0.075	20.08	7,382	
		3	7	0.3	0.053	0.48	609	
653	Explosive, Designolle powder; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.104	31.29	9,904	
		1	2	0.4	0.086	24.07	8,330	
		1	3	0.4	0.087	24.44	8,416	
		1	4	0.4	0.093	26.69	8,925	
		1	5	0.4	0.080	21.96	7,836	
		1	6	0.4	0.076	20.46	7,473	
		3	7	0.3	0.039	0.33	475	
654	Explosive, Designolle powder; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 1, full; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 3½ feet.	1	1	0.4	0.152	53.64	14,216	Gas check out.
		1	2	0.4	0.121	38.52	11,398	
		1	3	0.4	0.110	33.62	10,412	
		1	4	0.4	0.118	37.16	11,126	
		1	5	0.4	0.112	34.50	10,590	
		1	6	0.4	0.090	25.57	8,674	
		3	7	0.3	0.083	0.87	910	
655	Explosive, Designolle powder; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 1, full; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.130	42.56	12,183	
		1	2	0.4	0.122	39.00	11,491	
		1	3	0 4	0.128	41.70	12,018	
		1	4	0.4	0.134	44.67	12,578	
		1	5	0.4	0.091	25.94	8,758	
		1	6	0.4	0.105	31.62	9,992	
		3	7	0.3	0.079	0.81	866	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
656	Explosive, Designolle powder; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 1, full; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.115	35.82	10,857	
		1	2	0.4	0.127	41.28	11,935	
		1	3	0.4	0.110	33.62	10,412	
		1	4	0.4	0.129	42.13	12,100	
		1	5	0.4	0.097	28.28	9,276	
		1	6	0.4	0.097	28.28	9,276	
		3	7	0.3	0.109	1.25	1,162	
657	Explosive, Designolle powder; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 4½ feet; large boil.	1	1	0.4	0.165	60.43	15,390	
		1	2	0.4	0.138	46.59	12,939	
		1	3	0.4	0.110	33.62	10,412	
		1	4	0.4	0.114	35.38	10,768	
		1	5	0.4	0.105	31.62	9,992	
		1	6	0.4	0.117	36.71	11,036	
		3	7	0.3	0.087	0.93	954	
658	Explosive, Designolle powder, ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.165	60.43	15,390	
		1	2	0.4	0.117	36.71	11,036	
		1	3	0.4	0.137	46.13	12,851	
		1	4	0.4	0.123	39.47	11,584	
		1	5	0.4	0.107	32.42	10,160	
		1	6	0.4	0.097	28.28	9,276	
		3	7	0.3	0.102	1.14	1,091	
659	Explosive, Designolle powder; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.167	61.50	15,569	
		1	2	0.4	0.129	42.13	12,100	
		1	3	0.4	0.121	38.52	11,398	
		1	4	0.4	0.134	44.67	12,578	
		1	5	0.4	0.104	31.29	9,904	
		1	6	0.4	0.103	30.85	9,816	
		3	7	0.3	0.132	1.64	1,387	
660	Explosive, Designolle powder; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 5 feet; boil hardly became a dome.	1	1	0.4	0.225	97.75	21,210	
		1	2	0.4	0.171	63.64	15,928	
		1	3	0.4	0.152	53.64	14,216	
		1	4	0.4	0.172	64.18	16,018	
		1	5	0.4	0.149	51.34	13,949	
		1	6	0.4	0.147	50.73	13,768	
		3	7	0.3	0.159	2.18	1,679	
661	Explosive, Designolle powder; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Normal.	1	1	0.4	0.164	59.92	15,303	
		1	2	0.4	0.160	57.90	14,957	
		1	3	0.4	0.159	57.35	14,862	
		1	4	0.4	0.166	60.96	15,479	
		1	5	0.4	0.137	46.13	12,851	
		1	6	0.4	0.145	50.12	13,587	
		3	7	0.3	0.168	2.36	1,772	
662	Explosive, Designolle powder; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 5 feet in a 3-foot dome.	1	1	0.4	0 175	65.80	16,290	
		1	2	0.4	0.162	58.91	15,130	
		1	3	0.4	0.149	51.34	13,949	
		1	4	0.4	0.167	61.50	15,569	
		1	5	0.4	0.142	48.56	13,303	
		1	6	0.4	0.140	47.52	13,113	
		3	7	0.3	0.161	2.22	1,699	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
663	Explosive, picric powder; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 2¼ feet in a 2½-foot dome.	1	1	0. 4	0. 212	88. 42	19, 882	
		1	2	0. 4	0. 166	60. 96	15, 479	
		1	3	0. 4	0. 199	79. 81	18, 524	
		1	4	0. 4	0. 178	67. 52	16, 570	
		1	5	0. 4	0. 152	53. 64	14, 216	
		1	6	0. 4	0. 136	45. 66	12, 764	
		3	7	0. 3	0. 251	4. 42	2, 698	
664	Explosive, picric powder; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 4¼ feet; a 2-foot boil after it had sunk.	1	1	0. 4	0. 213	89. 13	19, 938	
		1	2	0. 4	0. 175	65. 80	16, 290	
		1	3	0. 4	0. 177	66. 95	16, 477	
		1	4	0. 4	0. 185	71. 52	17, 220	
		1	5	0. 4	0. 176	66. 37	16, 383	
		1	6	0. 4	0. 168	62. 03	15, 658	
		3	7	0. 3	0. 201	3. 07	2, 113	
66	Explosive, picric powder; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 75 feet; case, can No. 2. sawdust tamping; ignition, Laflin & Rand dynamo, 1 service low tension fuze. Effects: Buoy rose 2½ feet; dome 2½ feet high rose on one side of it. Last shot fired in 1879.	1	1	0. 4	0. 179	68. 10	16, 664	
		1	2	0. 4	0. 176	66. 37	16, 383	
		1	3	0. 4	0. 173	64. 72	16, 109	
		1	4	0. 4	0. 177	66. 95	16, 477	
		1	5	0. 4	0. 167	61. 50	15, 569	
		1	6	0. 4	0. 162	58. 91	15, 130	
		3	7	0. 3	0. 220	3. 54	2, 320	
666	Explosive, explosive gelatine; ring, 4 foot; charge, 1 pound; submergence, 83 feet; depth of water, 85 feet; case, fuze can, sawdust tamping; ignition, Laflin & Rand machine, 1 service low tension fuze. Effects: Buoy rose 1.5 feet; small upward boiling.	1	1	0. 4	0. 097	28. 28	9, 276	
		1	2	0. 4	0. 184	......	......	Hammered
		1	3	0. 4	0. 086	24. 07	8, 330	
		1	4	0. 4	0. 096	27. 86	9, 184	
		1	5	0. 4	0. 086	24. 07	8, 330	
		1	6	0. 4	0. 082	22. 65	7, 999	
		3	7	0. 3	0. 055	0. 50	630	
667	Explosive, explosive gelatine; ring, 4 foot; charge, 1 pound; submergence, 33 feet; depth of water, 85 feet; case, fuze can tamped with sawdust; ignition, Laflin & Rand machine, 1 service low tension fuze. Effects: Three distinct sounds and larger boil than with last shot; buoy rose 2.2 feet.	1	1	0. 4	0. 093	26. 69	8, 925	
		1	2	0. 4	0. 219	......	......	Hammered.
		1	3	0. 4	0. 080	21. 96	7, 836	
		1	4	0. 4	0. 108	32. 82	10, 244	
		1	5	0. 4	0. 088	24. 82	8, 502	
		1	6	0. 4	0. 069	18. 08	6, 884	
		3	7	0. 3	0. 075	0. 75	825	
668	Explosive, explosive gelatine; ring, 4 foot; charge, 1 pound; submergence, 33 feet; depth of water, 85 feet; case, fuze can, tamped with sawdust; ignition, Laflin & Rand machine, 1 service low tension fuze. Effects: Buoy rose 1.5 feet; medium boiling.	1	1	0. 4	0. 113	34. 94	10, 679	
		1	2	0. 4	0. 168	......	......	Disfigured.
		1	3	0. 4	0. 090	25. 57	8, 674	
		1	4	0. 4	0. 099	29. 13	9, 460	
		1	5	0. 4	0. 081	22. 31	7, 918	
		1	6	0. 4	0. 083	23. 00	8, 080	
		3	7	0. 3	0. 070	0. 70	788	
669	Explosive, explosive gelatine; ring, 4 foot; charge, 2 pounds; submergence, 83 feet; depth of water, 85 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine, 1 low tension fuze. Effects: Buoy rose 2 feet; large boil appeared in 6 seconds; three sounds.	1	1	0. 4	0. 151	53. 14	14, 128	
		1	2	0. 4	0. 123	39. 47	11, 584	
		1	3	0. 4	0. 105	31. 62	9, 992	
		1	4	0. 4	0. 129	42. 13	12, 100	
		1	5	0. 4	0. 093	26. 69	8, 925	
		1	6	0. 4	0. 100	29. 55	9, 552	
		3	7	0. 3	0. 127	1. 55	1, 336	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
670	Explosive, explosive gelatine; ring, 4 foot; charge, 2 pounds, submergence, 33 feet; depth of water, 85 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine, 1 low tension fuze. Effects: Buoy rose 2.5 feet; small boil appeared in 6.5 seconds.	1	1	0.4	0.102	30.42	9,728	
		1	2	0.4	0.146	50.42	13,678	
		1	3	0.4	0.092	26.32	8,841	
		1	4	0.4	0.109	33.22	10,328	
		1	5	0.4	0.081	22.81	7,918	
		1	6	0.4	0.089	25.19	8,588	
		3	7	0.3	0.134	1.67	1,408	
671	Explosive, explosive gelatine; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine, 1 low tension fuze. Effects: Buoy rose 2 feet; small boil in 5 seconds.	1	1	0.4	0.118	37.16	11,126	
		1	2	0.4	0.104	31.29	9,904	
		1	3	0.4	0.065	16.73	6,537	
		1	4	0.4	0.085	23.69	8,244	
		1	5	0.4	0.070	18.42	6,971	
		1	6	0.4	0.078	21.21	7,654	
		3	7	0.3	0.129	1.58	1,357	
672	Explosive, explosive gelatine; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine, 1 low tension fuze. Effects: Buoy rose 2 feet; very small boil appeared in 7 seconds.	1	1	0.4	0.141	48.04	13,208	
		1	2	0.4	0.129	42.13	12,100	
		1	3	0.4	0.064	16.42	6,453	
		1	4	0.4	0.080	21.96	7,836	
		1	5	0.4	0.068	17.74	6,797	
		1	6	0.4	0.060	15.15	6,119	
		3	7	0.3	0.061	0.59	701	
673	Explosive, explosive gelatine; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine, 1 low tension fuze. Effects: Buoy rose 2.5 feet; small dome appeared in 4 seconds.	1	1	0.4	0.159	57.35	14,862	
		1	2	0.4	0.144	49.60	13,492	
		1	3	0.4	0.130	42.56	12,183	
		1	4	0.4	0.153	54.15	14,304	
		1	5	0.4	0.140	47.52	13,113	
		1	6	0.4	0.137	46.13	12,851	
		3	7	0.3	0.232	3.87	2,462	
674	Explosive, explosive gelatine; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine, 1 low tension fuze. Effects: Buoy rose 2.2 feet; dome 2 feet high appeared in 3.5 seconds.	1	1	0.4	0.158	56.80	14,766	
		1	2	0.4	0.134	44.67	12,578	
		1	3	0.4	0.123	39.47	11,584	
		1	4	0.4	0.115	35.82	10,857	
		1	5	0.4	0.119	37.60	11,215	
		1	6	0.4	0.119	37.60	11,215	
		3	7	0.3	0.215	3.41	2,264	
675	Explosive, explosive gelatine; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 2, tamped with sawdust; ignition, Laflin & Rand machine, 1 low tension fuze. Effects: Buoy rose 3.7 feet; a dome 3 feet high appeared in 2 seconds. A duplicate of this shot failed to explode; the fuze burst open the can; charge recovered.	1	1	0.4	0.269	132.0	25,907	Broke clutch.
		1	2	0.4	0.229	100.7	21,626	
		1	3	0.4	0.217	92.0	20,366	
		1	4	0.4	0.222	95.6	20,898	
		1	5	0.4	0.208	85.7	19,430	
		1	6	0.4	0.189	73.7	17,576	
		3	7	0.3	0.270	5.0	2,934	
676	Explosive, explosive gelatine; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 2, tamped with sawdust; ignition, Laflin & Rand machine, 1 low tension fuze. Effects: Buoy rose 4 feet; dome of water 3 feet high.	1	1	0.4	0.229	100.7	21,626	
		1	2	0.4	0.163	59.4	15,217	
		1	3	0.4	0.177	67.0	16,477	
		1	4	0.4	0.172	64.2	16,018	
		1	5	0.4	0.161	58.4	15,044	
		1	6	0.4	0.154	54.7	14,392	
		3	7	0.3	0.258	4.7	2,791	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
677	Explosive, explosive gelatine; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 2, tamped with sawdust; ignition, Laflin & Rand machine, 1 low tension fuze. Effects: Buoy rose 4.5 feet and disappeared in dome 3 to 4 feet high; the shackle of lowering rope parted, but guard rope and suspension rope held.	1	1	0.4	0.181	69.2	16,850	
		1	2	0.4	0.202	81.8	18,833	
		1	3	0.4	0.151	53.1	14,128	
		1	4	0.4	0.177	67.0	16,477	
		1	5	0.4	0.163	59.4	15,217	
		1	6	0.4	0.140	47.5	13,113	
		3	7	0.3	0.187	2.8	1,977	
678	Explosive, explosive gelatine; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 1, tamped with sawdust; ignition, Laflin & Rand machine, 2 low tension fuzes. Effects: Buoy rose 2 feet; small boil appeared after several seconds. A charge of 4 pounds in a No. 2 can, with 1 low tension fuze, then failed, the fuze bursting open the can; the charge was recovered.	1	1	0.4	0.171	63.6	15,928	
		1	2	0.4	0.189	73.7	17,576	
		1	3	0.4	0.074	19.8	7,300	
		1	4	0.4	0.059	14.8	6,028	
		1	5	0.4	0.053	12.9	5,486	
		1	6	0.4	0.048	11.4	5,039	
		3	7	0.3	0.032	0.3	389	
679	Explosive, explosive gelatine; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand machine, 1 low tension fuze. Effects: Buoy rose 4 feet in large dome.	1	1	0.4	0.117	36.7	11,036	
		1	2	0.4	0.164	59.9	15,303	
		1	3	0.4	0.118	37.2	11,126	
		1	4	0.4	0.140	47.5	13,113	
		1	5	0.4	0.089	25.2	8,568	
		1	6	0.4	0.125	40.4	11,770	
		3	7	0.3	0.220	3.5	2,320	
680	Explosive, explosive gelatine; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 2, sawdust tamping; ignition, Laflin & Rand machine, 1 low tension fuze. Effects: Buoy rose 4 feet in a 3-foot dome.	1	1	0.4	0.069	18.1	6,884	
		1	2	0.4	0.090	25.6	8,674	
		1	3	0.4	0.072	19.1	7,135	
		1	4	0.4	0.078	21.2	7,654	
		1	5	0.4	0 034	7.4	3,803	
		1	6	0.4	0.039	8.8	4.264	
		3	7	0.3	0.190	2.8	2,008	
681	Explosive, explosive gelatine; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 85 feet; case, can No. 1, full; ignition, Laflin & Rand machine, 1 low tension fuze. Effects: Buoy rose 4.5 feet; dome appeared, but smaller than before.	1	1	0.4	0.131	43.1	12,282	
		1	2	0.4	0.109	32.2	10,328	
		1	3	0.4	0.121	38.5	11,398	
		1	4	0.4	0.113	34.9	10,679	
		1	5	0.4	0.086	24.1	8,330	
		1	6	0.4	0.102	30.4	9,728	
		3	7	0.3	0:142	1.8	1,484	
682	Explosive, explosive gelatine; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 90 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine, with 1 low tension fuze and 3 ounces dry gun-cotton. Effects: Buoy rose 3.5 feet; large boil appeared in few seconds.	1	1	0.4	0.164	59.9	15,308	
		1	2	0.4	0.171	63.6	15,928	
		1	3	0.4	0.196	77.9	18,221	
		1	4	0.4	0.189	73.7	17,576	
		1	5	0.4	0.176	66.4	16,383	
		1	6	0.4	0.190	74.3	17,665	
		3	7	0.3	0.145	1.9	1,517	
683	Explosive, explosive gelatine; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 90 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine and 1 low tension fuse, with 3 ounces dry gun-cotton. Effects: Buoy rose 4.5 feet with small dome.	1	1	0.4	0.208	85.7	19,430	
		1	2	0.4	0.228	99.9	21,522	
		1	3	0.4	0.241	109.6	22,789	
		1	4	0.4	0.233	103.6	22,045	
		1	5	0.4	0.194	76.6	18,029	Gauge-pin jammed.
		1	6	0.4	0.219	93.5	20,582	
		3	7	0.3	0.244	4.2	2,617	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
684	Explosive, explosive gelatine; ring, 4 foot; charge, 2 pounds; submergence, 33 feet; depth of water, 90 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine and 1 low tension fuze, with 3 ounces of loose dynamite in a rubber bag. Effects: Buoy rose 2 feet; small boil appeared.	1	1	0.4	0.120	38.1	11,305	
		1	2	0.4	0.167	61.5	15,569	
		1	3	0.4	0.110	33.6	10,412	
		1	4	0.4	0.098	28.7	9,368	
		1	5	0.4	0.075	20.1	7,382	
		1	6	0.4	0.090	25.6	8,674	
		3	7	0.3	0.101	1.1	1,081	
685	Explosive, explosive gelatine; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 90 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine and 1 low tension fuze, with 3 ounces of loose dynamite in rubber bag. Effects: Buoy rose 4.5 feet and subsided in a 2-foot dome of water.	1	1	0.4	0.149	51.3	13,949	
		1	2	0.4	0.166	61.0	15,479	
		1	3	0.4	0.151	53.1	14,128	
		1	4	0.4	0.192	75.5	17,847	
		1	5	0.4	0.132	43.6	12,381	
		1	6	0.4	0.143	49.1	13,397	
		3	7	0.3	0.165	2.3	1,736	
686	Explosive, explosive gelatine; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 90 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine and 1 low tension fuze, with 3 ounces of loose dynamite in rubber bag. Effects: Buoy rose 4.5 feet; dome 3 feet high.	1	1	0.4	0.233	103.6	22,045	
		1	2	0.4	0.219	93.5	20,582	
		1	3	0.4	0.272	134.4	26,226	
		1	4	0.4	0.269	132.0	25,907	
		1	5	0.4	0.244	111.9	23,116	
		1	6	0.4	0.252	118.1	24,056	
		3	7	0.3	0.207	3.2	2,178	
687	Explosive, explosive gelatine; ring, 4 foot; charge, 4 pounds; submergence, 33 feet; depth of water, 90 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine and 1 low tension fuze, with 3 ounces of dry gun-cotton. Effects: Buoy rose 4 feet; dome 3 feet high.	1	1	0.4	0.244	111.9	23,116	
		1	2	0.4	0.231	102.1	21,835	
		1	3	0.4	0.286	146.4	27,758	
		1	4	0.4	0.254	119.7	24,272	
		1	5	0.4	0.213	89.1	19,938	
		1	6	0.4	0.250	116.5	23,840	
		3	7	0.3	0.186	2.8	1,967	
688	Explosive, explosive gelatine; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 90 feet; case, can No. 1, full; ignition, Laflin & Rand machine and 1 low tension fuze, with 3 ounces of dry gun-cotton. Effects: Buoy rose and fell over in a 5-foot dome; heavy shock, breaking bolt of shackle.	1	1	0.4	0.284	148.9	28,082	
		1	2	0.4	0.230	110.4	21,730	
		1	3	0.4	0.296	155.0	28,842	
		1	4	0.4	0.250	116.5	23,840	
		1	5	0.4	0.234	104.4	22,150	
		1	6	0.4	0.247	114.2	23,531	
		3	7	0.3	0.274	5.2	2,980	
689	Explosive, explosive gelatine; ring, 4 foot; charge, 5 pounds; submergence, 33 feet; depth of water, 90 feet; case, can No. 1, full; ignition, Laflin & Rand machine and 1 low tension fuze, with 3 ounces of loose dynamite in rubber bag. Effects: Buoy rose 4.5 feet and was buried in a 5-foot dome; heavy shock, breaking wire suspension rope and strap.	1	1	0.4	0.276	137.8	26,664	
		1	2	0.4	0.275	136.9	26,550	
		1	3	0.4	0.306	165.0	30,058	
		1	4	0.4	0.262	126.3	25,156	
		1	5	0.4	0.251	117.3	23,948	
		1	6	0.4	0.235	105.1	22,255	
		3	7	0.3	0.243	4.2	2,604	
690	Explosive, explosive gelatine; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 1 and sawdust tamping; ignition, Laflin & Rand machine and 1 low tension fuze, with 3 ounces of dry gun-cotton in middle. Effects: After loading, this charge was packed in ice for 79 hours and when fired was frozen hard; buoy rose 4 feet; large boil followed by small dome.	1	1	0.4	0.204	83.2	19,041	
		1	2	0.4	0.179	68.1	16,664	
		1	3	0.4	0.179	68.1	16,664	
		1	4	0.4	0.215	90.6	20,150	
		1	5	0.4	0.182	69.8	16,942	
		1	6	0.4	0.199	79.8	18,524	
		3	7	0.3	0.147	1.9	1,541	

Details of experiments with the Rings—Continued.

Original number.	Details of experiment.	Gauge.		Lead cylinder.		Per square inch.		Remarks.
		Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	
		No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Lbs.*	
691	Explosive, explosive gelatine; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine and 1 low tension fuze, with 3 ounces of loose dynamite in rubber bag in middle. Effects: Same as last shot as to freezing and effects of explosion.	1	1	0.4	0.216	91.3	20,258	
		1	2	0.4	0.246	113.5	23,428	
		1	3	0.4	0.177	67.0	16,477	
		1	4	0.4	0.258	.....	......	Rounded lead.
		1	5	0.4	0.171	63.6	15,928	
		1	6	0.4	0.230	101.4	21,730	
		3	7	0.3	.....	.....	......	Failed.
692	Explosive, explosive gelatine; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine and 1 low tension fuze, with 3 ounces of loose dynamite. Effects: Buoy rose 4 feet; small dome. Some of the charges of this 3-pound series were in the white opaque state, and others a yellow jelly; no difference in registered pressures.	1	1	0.4	0.229	100.8	21,626	
		1	2	0.4	0.270	.....	......	Clutch broken.
		1	3	0.4	0.213	89.1	19,930	
		1	4	0.4	0.229	100.8	21,626	
		1	5	0.4	0.209	86.4	19,525	
		1	6	0.4	0.173	64.7	16,109	
		3	7	0.3	.....	.....	......	Failed.
693	Explosive, explosive gelatine; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine and 1 low tension fuze, with 3 ounces of loose dynamite in rubber bag. Effects: Buoy rose 4 feet; dome 2 feet high.	1	1	0.4	0.165	60.4	15,390	
		1	2	0.4	0.149	51.3	13,949	
		1	3	0.4	0.163	59.4	15,217	
		1	4	0.4	0.174	65.3	16,199	
		1	5	0.4	0.163	59.4	15,217	
		1	6	0.4	0.149	51.3	13,949	
		3	7	0.3	0.160	2.2	1,690	
694	Explosive, explosive gelatine; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine and 1 low tension fuze, with 3 ounces of loose dynamite in rubber bag. Effects: Broke shackle bolt releasing buoy; guard rope held; dome 2 feet high.	1	1	0.4	0.159	57.4	14,862	
		1	2	0.4	0.199	79.8	18,524	
		1	3	0.4	0.189	73.7	17,567	
		1	4	0.4	0.186	77.9	18,221	
		1	5	0.4	0.143	49.1	13,397	
		1	6	0.4	0.149	51.3	13,949	
		3	7	0.3	0.184	2.7	1,943	
695	Explosive, explosive gelatine; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine and 1 low tension fuze, with 3 ounces of dry guncotton. Effects: Buoy rose 3 feet; small dome.	1	1	0.4	0.203	82.5	18,937	
		1	2	0.4	0.234	104.4	22,150	
		1	3	0.4	0.227	99.2	21,418	
		1	4	0.4	0.216	91.3	20,258	
		1	5	0.4	0.139	47.1	13,026	
		1	6	0.4	0.193	76.1	17,938	
		3	7	0.3	0.200	3.1	2,102	
696	Explosive, explosive gelatine; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine and 1 low tension fuze, with 3 ounces of dry guncotton. Effects: Buoy rose and sunk back under a 2-foot dome.	1	1	0.4	0.199	79.8	18,524	
		1	2	0.4	0.166	61.0	15,479	
		1	3	0.4	0.229	100.7	21,626	
		1	4	0.4	0.240	108.8	22,780	
		1	5	0.4	0.160	57.9	14,957	
		1	6	0.4	0.199	79.8	18,524	
		3	7	0.3	0.133	1.7	1,398	
697	Explosive, explosive gelatine; ring, 4 foot; charge, 3 pounds; submergence, 33 feet; depth of water, 80 feet; case, can No. 1, sawdust tamping; ignition, Laflin & Rand machine and 1 low tension fuze, with 3 ounces of dry guncotton. Effects: Buoy rose 3 feet; dome 2 feet high.	1	1	0.4	0.200	80.5	18,625	
		1	2	0.4	0.199	79.8	18,524	
		1	3	0.4	0.246	113.5	23,428	
		1	4	0.4	0.199	79.8	18,524	
		1	5	0.4	0.190	74.3	17,665	
		1	6	0.4	0.192	75.5	17,847	
		3	7	0.3	0.192	2.9	2,025	

APPENDIX B.

DETAILS OF EXPERIMENTS WITH THE CRATE.

SHOT 195—FIRED AUGUST 29, 1872.

TOP OF CRATE.						BOTTOM OF CRATE.					
Gauge.		Lead cylinder.		Per square inch.		Gauge.		Lead cylinder.		Per square inch.	
Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.
No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*	*No.*		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*
3	1	0.4	0.025	0.29	484	3	1	0.4	0.015	0.17	307
3	2	0.4	0.017	0.19	325	3	2	0.4	0.040	0.53	654
3	3	0.4	0.018	0.19	335	3	3	0.4	0.020	0.21	353
3	4	0.4	0.023	0.26	404	3	4	0.4	0.021	0.23	370
3	5	0.4	0.035	0.44	578	3	5	0.4	0.038	0.49	624
3	6	0.4	0.050	0.71	795	3	6	0.4	0.041	0.55	669
3	7	0.4	0.038	0.49	624	3	7	0.4	0.034	0.42	562
3	8	0.4	0.030	0.35	496	3	8	0.4	0.032	0.39	529
3	9	0.4	0.045	0.62	727	3	9	0.4	0.042	0.57	683
3	10	0.4	0.042	0.57	683	3	10	0.4	0.041	0.55	669
3	11	0.4	0.038	0.49	624	3	11	0.4	0.040	0.53	654
3	12	0.4	0.043	0.58	698	3	12	0.4	0.041	0.55	669
3	13	0.4	0.066	1.03	1,018	3	13	0.4	0.071	1.12	1,078
3	14	0.4	0.057	0.84	887	3	14	0.4	0.075	1.20	1,129
3	15	0.4	0.086	1.45	1,279	3	15	0.4	0.084	1.41	1,254
3	16	0.4	0.076	1.22	1,142	3	16	0.4	0.067	1.05	1,030
3	17	0.4	0.137	2.74	1,957	3	17	0.4	0.167	3.68	2,373
3	18	0.4	0.112	2.06	1,618	3	18	0.4	0.177	4.04	2,356
3	Buoy 1	0.4	0.046	0.64	741	3	Buoy 2	0.4	0.038	0.49	624

NOTES.

Explosive, dynamite No. 1; charge, 5 pounds; submergence, 42 feet; depth of water, 112 feet; case, can No. 2, sawdust tamping; ignition, Smith battery, 2 Mowbray fuzes. Effects: ringing explosion; buoys did not move; water did not begin boiling for several seconds; buoys each read 11½ feet, the crate being level.

SHOT 217—FIRED SEPTEMBER 24, 1872.

3	1	0.4	0.023	0.26	404	3	1	0.4	0.020	0.21	353
3	2	0.4	0.042	0.57	683	3	2	0.4	0.017	0.19	325
3	3	0.4	0.025	0.29	438	3	3	0.4	0.021	0.23	370
3	4	0.4	0.017	0.19	325	3	4	0.4	0.016	0.18	316
3	5	0.4	0.046	0.64	741	3	5	0.4	0.034	0.42	562
3	6	0.4	0.037	0.48	608	3	6	0.4	0.034	0.42	562
3	7	0.4	0.028	0.33	473	3	7	0.4	0.035	0.44	578
3	8	0.4	0.025	0.29	438	3	8	0.4	0.025	0.29	438
3	9	0.4	0.072	1.14	1,091	3	9	0.4	0.034	0.42	562
3	10	0.4	0.044	0.60	713	3	10	0.4	0.045	0.62	727
3	11	0.4	0.035	0.44	578	3	11	0.4	0.053	0.76	834
3	12	0.4	0.036	0.46	593	3	12	0.4	0.039	0.51	639
3	13	0.4	0.072	1.14	1,091	3	13	0.4	0.062	0.94	957
3	14	0.4	0.070	1.10	1,065	3	14	0.4	0.064	0.99	990
3	15	0.4	0.081	1.33	1,210	3	15	0.4	0.070	1.10	1,065
3	16	0.4	0.064	0.99	990	3	16	0.4	0.058	0.85	899
3	17	0.4	0.176	4.01	2,521	3	17	0.4	0.150	3.15	2,147
3	18	0.4	0.164	3.58	2,339	3	18	0.4	0.155	3.29	2,210
3	Buoy 1	0.4	0.056	0.82	874	3	Buoy 2	0.4	0.067	1.05	1,030

NOTES.

Explosive, dynamite No. 1; charge, 5 pounds; submergence, about 36 feet; depth of water, 100 feet; axis inclined 25°; case, can No. 2, sawdust tamping; ignition, Smith battery, 2 Mowbray and 1 Browne No. 4 fuzes. Effects: Sharp explosion, throwing spray upward from water surface; buoys gave three distinct sounds; a 1-foot boil rose near buoy 1; buoy 1 read 13.3, and buoy 2, 10.0—latter supporting deeper end of crate.

Details of experiments with the Crate—Continued.

SHOT 218—FIRED SEPTEMBER 24, 1872.

TOP OF CRATE.						BOTTOM OF CRATE.					
Gauge.		Lead cylinder.		Per square inch.		Gauge.		Lead cylinder.		Per square inch.	
Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.
No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*	*No.*		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*
3	1	0.4	0.035	0.44	578	3	1	0.4	0.026	0.30	450
3	2	0.4	0.045	0.62	727	3	2	0.4	0.034	0.42	562
3	3	0.4	0.022	0.24	387	3	3	0.4	0.019	0.20	344
3	4	0.4	0.030	0.35	496	3	4	0.4	0.035	0.44	578
3	5	0.4	0.040	0.53	654	3	5	0.4	0.050	0.71	795
3	6	0.4	0.050	0.71	795	3	6	0.4	0.036	0.46	593
3	7	0.4	0.036	0.46	593	3	7	0.4	0.025	0.29	438
3	8	0.4	0.028	0.33	473	3	8	0.4	0.029	0.34	484
3	9	0.4	0.068	1.06	1,041	3	9	0.4	0.055	0.80	861
3	10	0.4	0.048	0.67	768	3	10	0.4	0.072	1.14	1,091
3	11	0.4	0.075	1.20	1,129	3	11	0.4	0.057	0.84	887
3	12	0.4	0.074	1.18	1,116	3	12	0.4	0.061	0.91	941
3	13	0.4	0.068	1.06	1,041	3	13	0.4	0.065	1.01	1,006
3	14	0.4	0.067	1.05	1,030	3	14	0.4	0.065	1.01	1,006
3	15	0.4	0.078	1.27	1,169	3	15	0.4	0.057	0.84	887
3	16	0.4	0.066	1.03	1,018	3	16	0.4	0.115	2.13	1,655
3	17	0.4	0.181	4.18	2,594	3	17	0.4	0.198	4.79	2,839
3	18	0.4	0.148	3.09	2,116	3	18	0.4	0.154	3.26	2,197
3	Buoy 1	0.4	0.045	0.62	727	3	Buoy 2	0.4	0.037	0.48	606

NOTES.

Explosive, dynamite No. 1; charge, 5 pounds; submergence, about 36 feet; depth of water, 87 feet; axis inclined 25°; case, can No. 2, sawdust tamping; ignition, Smith battery, 2 Browne No. 4 fuzes. Effects: Sharp explosion; buoys did not rise; dome of water 2 feet high; buoy 1 read 14 feet, buoy 2 read 10 feet—the latter supporting the deeper end of crate.

SHOT 225—FIRED OCTOBER 22, 1872.

3	1	0.4	0.035	0.44	578	3	1	0.4	0.010	0.10	215
3	2	0.4	0.016	0.18	316	3	2	0.4	0.015	0.17	307
3	3	0.4	0.032	0.39	529	3	3	0.4	0.016	0.18	316
3	4	0.4	0.025	0.29	438	3	4	0.4	0.023	0.26	404
3	5	0.4	0.040	0.53	654	3	5	0.4	0.046	0.64	741
3	6	0.4	0.045	0.62	727	3	6	0.4	0.032	0.39	529
3	7	0.4	0.036	0.46	593	3	7	0.4	0.033	0.40	545
3	8	0.4	0.020	0.21	353	3	8	0.4	0.025	0.29	438
3	9	0.4	0.057	0.84	887	3	9	0.4	0.040	0.53	654
3	10	0.4	0.050	0.71	795	3	10	0.4	0.043	0.58	698
3	11	0.4	0.034	0.42	562	3	11	0.4	0.030	0.35	496
3	12	0.4	0.045	0.62	727	3	12	0.4	0.039	0.51	639
3	13	0.4	0.075	1.20	1,129	3	13	0.4	0.062	0.94	957
3	14	0.4	0.056	0.82	874	3	14	0.4	0.062	0.94	957
3	15	0.4	0.064	0.90	990	3	15	0.4	0.098	1.72	1,435
3	16	0.4	0.091	1.55	1,336	3	16	0.4	0.066	1.03	1,018
3	17	0.4	0.166	3.65	2,367	3	17	0.4	0.153	3.23	2,185
3	18	0.4	0.144	2.95	2,056	3	18	0.4	0.151	3.18	2,160
3	Buoy 1	0.4	0.045	0.62	727	3	Buoy 2	0.4	0.042	0.57	683

NOTES.

Explosive, dynamite No. 1; charge, 5 pounds; submergence, 29 feet; depth of water, 80 feet; axis of crate level; case, can No. 2, sawdust tamping; ignition, Smith battery, 1 Browne No. 4 fuze. Effects: Three loud sounds from buoys, which did not move; dome of water 6 to 8 feet high; both buoys read 11½ feet.

Details of experiments with the Crate—Continued.

SHOT 226—FIRED OCTOBER 22, 1872.

TOP OF CRATE.						BOTTOM OF CRATE.					
Gauge.		Lead cylinder.		Per square inch.		Gauge.		Lead cylinder.		Per square inch.	
Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.
No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*	*No.*		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*
3	1	0.4	0.041	0.55	669	3	1	0.4	0.029	0.34	484
3	2	0.4	0.040	0.53	654	3	2	0.4	0.068	1.06	1,041
3	3	0.4	0.037	0.48	608	3	3	0.4	0.030	0.35	496
3	4	0.4	0.040	0.53	654	3	4	0.4	0.034	0.42	562
3	5	0.4	0.059	0.87	912	3	5	0.4	0.064	0.99	990
3	6	0.4	0.080	1.31	1,196	3	6	0.4	0.103	1.84	1,498
3	7	0.4	0.064	0.99	990	3	7	0.4	0.059	0.87	912
3	8	0.4	0.058	0.85	899	3	8	0.4	0.119	2.24	1,712
3	9	0.4	0.098	1.72	1,435	3	9	0.4	0.108	1.96	1,565
3	10	0.4	0.085	1.43	1,268	3	10	0.4	0.113	2.09	1,630
3	11	0.4	0.079	1.29	1,182	3	11	0.4	0.084	1.41	1,254
3	12	0.4	0.084	1.41	1,254	3	12	0.4	0.108	1.96	1,565
3	13	0.4	0.133	2.63	1,903	3	13	0.4	0.148	3.09	2,116
3	14	0.4	0.130	2.55	1,865	3	14	0.4	0.125	2.39	1,786
3	15	0.4	0.115	2.13	1,655	3	15	0.4	0.151	3.18	2,160
3	16	0.4	0.148	3.09	2,116	3	16	0.4	0.160	3.47	2,290
3	17	0.4	0.266	7.77	3,921	3	17	0.4	0.294	9.19	4,385
3	18	0.4	0.278	8.37	4,120	3	18	0.4	0.295	9.25	4,403
3	Buoy 1	0.4	0.056	0.82	874	3	Buoy 2	0.4	0.058	0.85	899

NOTES.

Explosive, dynamite No. 1; charge, 10 pounds; submergence, 42 feet; depth of water, 85 feet; axis of crate level; case, can No. 2, full; ignition, Smith battery, and 1 Browne No. 4 fuze. Effects: Loud ring from buoys; spray thrown from water surface, followed by a dome 15 feet high and 25 feet base; shock severe. Both buoys read 11½ feet.

SHOT 293—FIRED NOVEMBER 14, 1872.

3	1	0.4	0.013	0.14	270	3	1	0.4	0.022	0.24	387
3	2	0.4	0.016	0.18	316	3	2	0.4	0.051	0.73	808
3	3	0.4	0.005	0.04	117	3	3	0.4	0.038	0.49	624
3	4	0.4	0.005	0.04	117	3	4	0.4	0.068	1.06	1,041
3	5	0.4	0.037	0.48	608	3	5	0.4	0.053	0.76	834
3	6	0.4	0.028	0.33	473	3	6	0.4	0.041	0.55	669
3	7	0.4	0.010	0.10	215	3	7	0.4	0.055	0.80	861
3	8	0.4	0.005	0.04	117	3	8	0.4	0.040	0.53	654
3	9	0.4	0.065	1.01	1,006	3	9	0.4	0.056	0.82	874
3	10	0.4	0.067	1.05	1,030	3	10	0.4	0.049	0.69	781
3	11	0.4	0.025	0.29	438	3	11	0.4	0.048	0.67	768
3	12	0.4	0.022	0.24	387	3	12	0.4	0.049	0.69	781
3	13	0.4	0.238	6.50	3,480	3	13	0.4	0.073	1.16	1,103
3	14	0.4	0.238	6.50	3,480	3	14	0.4	0.074	1.18	1,116
3	15	0.4	0.125	2.39	1,786	3	15	0.4	0.088	1.48	1,300
3	16	0.4	0.108	1.96	1,565	3	16	0.4	0.094	1.62	1,380
3	17	0.4	0.188	4.43	2,695	3	17	0.4	0.153	3.23	2,185
3	18	0.4	0.198	4.79	2,839	3	18	0.4	0.197	4.75	2,824

NOTES.

Explosive, dynamite No. 1; charge, 5 pounds; submergence, 6 feet; depth of water, 16 feet; crate hung from crane on wharf; axis level and top awash; case, can No. 2, sawdust tamping; ignition, Smith battery and 1 Browne No. 4 fuze. Effects: Jet 20 to 30 feet high; much mud thrown up.

Details of experiments with the Crate—Continued.

SHOT 343—FIRED SEPTEMBER 14, 1874.

TOP OF CRATE.						BOTTOM OF CRATE.					
Gauge.		Lead cylinder.		Per square inch.		Gauge.		Lead cylinder.		Per square inch.	
Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.
No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*	*No.*		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*
3	1	0.4	0.047	0.66	754	3	1	0.4	0.077	1.24	1,156
3	2	0.4	0.036	0.46	598	3	2	0.4	0.034	0.42	562
3	3	0.4	0.025	0.29	438	3	3	0.4	0.031	0.37	512
3	4	0.4	0.030	0.35	496	3	4	0.4	0.040	0.53	654
3	5	0.4	0.075	1.20	1,129	3	5	0.4	0.052	0.75	821
3	6	0.4	0.074	1.18	1,116	3	6	0.4	0.053	0.76	834
3	7	0.4	0.058	0.85	899	3	7	0.4	0.053	0.76	834
3	8	0.4	0.079	1.29	1,182	3	8	0.4	0.055	0.80	861
3	9	0.4	0.106	1.91	1,536	3	9	0.4	0.084	1.41	1,254
3	10	0.4	0.076	1.22	1,142	3	10	0.4	0.080	1.31	1,196
3	11	0.4	0.072	1.14	1,091	3	11	0.4	0.067	1.05	1,030
3	12	0.4	0.074	1.18	1,116	3	12	0.4	0.085	1.43	1,268
3	13	0.4	0.132	2.60	1,890	3	13	0.4	0.109	1.99	1,579
8	14	0.4	0.120	2.27	1,726	3	14	0.4	0.119	2.24	1,712
3	15	0.4	0.135	2.68	1,928	3	15	0.4	0 132	2.60	1,890
3	16	0.4	0.130	2.55	1,865	3	16	0.4	0.124	2.37	1,774
3	17	0.4	0.307	9.93	4,616	3	17	0.4	0.291	9.02	4,329
3	18	0.4	0.306	9.87	4,598	3	18	0.4	0.306	9.87	4,598
3	Buoy 1	0.4	0.040	0.53	654	3	Buoy 2	0.4	0.051	0.73	808

NOTES.

Explosive, dynamite No. 1; charge, 10 pounds; submergence, 42 feet; depth of water, 90 feet; axis of crate, horizontal; case, can No. 2, full; ignition, Farmer dynamo and 1 service low tension fuze. Effects: Several loud sounds; jet 8 to 10 feet high rose in 3½ seconds; shock severe; at 100 feet distance it threw off top of stove in cabin of schooner.

SHOT 344—FIRED SEPTEMBER 14, 1874.

3	1	0.4	0.056	0.82	874	3	1	0.4	0.060	0.89	925
3	2	0.4	0.062	0.94	957	3	2	0.4	0.060	0.89	925
3	3	0.4	0.040	0.53	654	3	3	0.4	0.056	0.82	874
3	4	0.4	0.056	0.82	874	3	4	0.4	0.049	0.69	781
3	5	0.4	0.065	1.01	1,006	3	5	0.4	......	......	......
3	6	0.4	0.101	1.79	1,474	3	6	0.4	0.076	1.22	1,142
3	7	0.4	0.072	1.14	1,091	3	7	0.4	0.082	1.36	1,225
3	8	0.4	0.072	1.14	1,091	3	8	0.4	0.060	0.89	925
3	9	0.4	0.101	1.79	1,474	3	9	0.4	0.086	1.45	1,279
3	10	0.4	0.129	2.52	1,849	3	10	0.4	0.097	1.69	1,422
3	11	0.4	0.067	1.05	1,030	3	11	0.4	0.092	1.57	1,351
3	12	0.4	0.081	1.33	1,210	3	12	0.4	0.091	1.55	1,336
3	13	0.4	0.149	3.11	2,132	3	13	0.4	0.128	2.49	1,833
3	14	0.4	0.177	4.04	2,536	3	14	0.4	0.171	3.83	2,445
3	15	0.4	0.136	2.71	1,942	3	15	0.4	0.158	3.40	2,258
3	16	0.4	0.136	2.71	1,942	3	16	0.4	0.140	2.83	2,000
3	17	0.4	0.344	12.16	5,283	3	17	0.4	0.346	12.30	5,327
3	18	0.4	0.264	7.67	3,888	3	18	0.4	0.311	10.16	4,688
3	Buoy 1	0.4	0.033	0.40	545	3	Buoy 2	0.4	0.086	1.45	1,279

NOTES.

Explosive, dynamite No. 1; charge, 10 pounds; submergence, about 36 feet; depth of water, 80 feet; axis of crate, inclined 25°; buoy 1 reads 13 feet, and buoy 2 10 feet, the latter supporting the deeper end of crate; case, can No. 2, full; ignition, Farmer dynamo and 1 service low tension fuze. Effects: Dome of water 15 feet high.

Details of experiments with the Crate—Continued.

SHOT 345—FIRED SEPTEMBER 14, 1874.

TOP OF CRATE.						BOTTOM OF CRATE.					
Gauge.		Lead cylinder.		Per square inch.		Gauge.		Lead cylinder.		Per square inch.	
Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.
No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*	*No.*		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*
3	1	0.4	0.083	1.38	1,239	3	1	0.4	0.052	0.75	821
3	2	0.4	0.053	0.76	834	3	2	0.4	0.063	0.96	974
3	3	0.4	0.030	0 35	496	3	3	0.4	0.054	0.78	847
3	4	0.4	0.039	0.51	639	3	4	0.4	0.072	1.14	1,091
3	5	0.4	0.057	0.84	887	3	5	0.4	0.102	1.81	1,486
3	6	0.4	0.099	1.74	1,449	3	6	0.4	0.080	1.31	1,196
3	7	0.4	0.072	1.14	1,091	3	7	0.4	0.038	0.49	624
3	8	0.4	0.062	0.94	957	3	8	0.4	0.067	1.05	1,030
3	9	0.4	0.107	1.94	1,550	3	9	0.4	0.099	1.74	1,449
3	10	0.4	......	......	......	3	10	0.4	0.084	1.41	1,254
3	11	0.4	0.073	1.16	1,103	3	11	0.4	0.073	1.16	1,103
3	12	0.4	0.104	1.86	1,510	3	12	0.4	0.089	1.50	1,310
3	13	0.4	0.142	2.89	2,028	3	13	0.4	0.169	3.75	2,414
3	14	0.4	0.159	3.43	2,274	3	14	0.4	......	......	......
3	15	0.4	0.147	3.05	2,101	3	15	0.4	0.145	2.98	2,070
3	16	0.4	0.108	1.96	1,565	3	16	0.4	0.167	3.68	2,373
3	17	0.4	0.282	8.57	4,185	3	17	0.4	0.349	12.57	5,401
3	18	0.4	0.268	7.87	3,954	3	18	0.4	0.341	11.96	5,227
3	Buoy 1	0.4	0.045	0.62	727	3	Buoy 2	0.4	0.067	1.05	1,030

NOTES.

Explosive, dynamite No. 1; charge, 10 pounds; submergence, about 36 feet; depth of water, 60 feet; axis of crate inclined 25°; buoy No. 1 read 13 and buoy No. 2 10, the latter supporting deeper end of crate; case can No. 2, full; ignition, Farmer machine and 1 service low tension fuze. Effects: Dome 15 feet high and 20 feet in diameter; shock knocked off top of stove in cabin of schooner, distant 80 feet; side of buoy 1 slightly corrugated, and crate transom over charge somewhat bent.

SHOT 346—FIRED SEPTEMBER 22, 1874.

3	1	0.4	0.024	0.27	421	3	1	0.4	......	......	......
3	2	0.4	0.008	0.08	176	3	2	0.4	0.017	0.19	325
3	3	0.4	0.052	0.75	821	3	3	0.4	0.031	0.37	512
3	4	0.4	0.034	0.42	562	3	4	0.4	0.042	0.57	683
3	5	0.4	0.027	0.31	461	3	5	0.4	0.025	0.29	438
3	6	0.4	0.024	0.27	421	3	6	0.4	0.023	0.26	404
9	7	0.4	0.037	0.48	608	3	7	0.4	0.054	0.78	847
3	8	0.4	0.043	0.58	698	3	8	0.4	0.029	0.34	484
3	9	0.4	0.034	0.42	562	3	9	0.4	0.039	0.51	639
3	10	0.4	0.025	0.29	438	3	10	0.4	0.039	0.51	639
3	11	0.4	0.038	0.49	624	3	11	0.4	0.059	0.87	912
3	12	0.4	0.065	1.01	1,006	3	12	0.4	0.037	0.48	608
3	13	0.4	0.056	0.82	874	3	13	0.4	0.063	0.96	974
3	14	0.4	0.108	1.96	1,565	3	14	0.4	0.064	0.99	990
3	15	0.4	0.077	1.24	1,156	3	15	0.4	......	......	......
3	16	0.4	0.104	1.86	1,510	3	16	0.4	0.076	1.22	1,142
3	17	0.4	0.170	3.79	2,430	3	17	0.4	0.196	4.72	2,810
3	18	0.4	0.166	3.65	2,367	3	18	0.4	0.182	4.22	2,608
3	L. buoy 1	0.4	0.064	0.99	990	3	S. buoy 1	0.4	0.055	0.80	861
3	L. buoy 2	0.4	0.047	0.66	754	3	S. buoy 2	0.4	0.067	1.05	1,030

NOTES.

Explosive, dynamite No. 1; charge, 5 pounds; submergence, 39 feet; depth of water, 88 feet; axis of crate inclined 53°; buoy No. 1 read 9.3 feet, and buoy No 2 12 feet, and they were 16½ feet apart; No. 1 supported deeper end of crate; two extra (ring) buoys were attached at No. 3 and No. 4 uprights to aid buoy No. 2; case, can No. 2, sawdust tamping; ignition, Farmer dynamo and 1 service low tension fuze Effects: Boil rose in 4 seconds around buoy No. 2.

Details of experiments with the Crate—Continued.

SHOT 347—FIRED SEPTEMBER 22, 1874.

TOP OF CRATE.						BOTTOM OF CRATE.					
Gauge.		Lead cylinder.		Per square inch.		Gauge.		Lead cylinder.		Per square inch.	
Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.
No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*	*No.*		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*
3	1	0.4	0.019	0.20	344	3	1	0.4	0.016	0.18	316
3	2	0.4	0.018	0.19	335	3	2	0.4	0.021	0.23	370
3	3	0.4	0.049	0.69	781	3	3	0.4	0.032	0.39	529
3	4	0.4	0.039	0.51	639	3	4	0.4	0.045	0.62	727
3	5	0.4	0.043	0.58	698	3	5	0.4	0.036	0.46	598
3	6	0.4	0.035	0.44	578	3	6	0.4	0.023	0.26	404
3	7	0.4	0.054	0.78	847	3	7	0.4	0.027	0.31	461
3	8	0.4	0.047	0.66	754	3	8	0.4	0.051	0.73	808
3	9	0.4	0.038	0.49	624	3	9	0.4	0.035	0.44	578
3	10	0.4	0.037	0.48	608	3	10	0.4	......	......	......
3	11	0.4	0.064	0.99	990	3	11	0.4	0.080	1.31	1,196
3	12	0.4	0.047	0.66	754	3	12	0.4	0.078	1.27	1,169
3	13	0.4	0.066	1.03	1,018	3	13	0.4	0.065	1.01	1,006
3	14	0.4	0.059	0.87	912	3	14	0.4	0.054	0.78	847
3	15	0.4	0.103	1.84	1,498	3	15	0.4	0.073	1.16	1,103
3	16	0.4	0.089	1.50	1,310	3	16	0.4	0.069	1.08	1,053
3	17	0.4	0.160	3.47	2,290	3	17	0.4	0.155	3.29	2,210
3	18	0.4	0.139	2.80	1,986	3	18	0.4	0.170	3.79	2,430
3	L. buoy 1	0.4	0.029	0.34	484	3	S. buoy 1	0.4	0.039	0.51	639
3	L. buoy 2	0.4	0.047	0.66	754	3	S. buoy 2	0.4	0.067	1.05	1,030

NOTES.

Explosive, dynamite No. 1; charge, 5 pounds: submergence, 39 feet; depth of water, 88 feet; axis of crate inclined 53°; arrangement of buoys, including the two extra ones, as in last shot; case, can No. 2, sawdust tamping; ignition, Farmer dynamo and 1 service low tension fuze. Effects: Boil rose in 3½ seconds very near buoy 2.

SHOT 348—FIRED SEPTEMBER 22, 1874.

3	1	0.4	0.065	1.01	1,006	3	1	0.4	0.052	0.75	821
3	2	0.4	0.040	0.53	654	3	2	0.4	0.059	0.87	912
3	3	0.4	0.074	1.18	1,116	3	3	0.4	0.044	0.60	713
3	4	0.4	0.057	0.84	887	3	4	0.4	0.041	0.55	669
3	5	0.4	0.102	1.81	1,486	3	5	0.4	0.081	1.33	1,210
3	6	0.4	0.121	2.29	1,738	3	6	0.4	0.080	1.31	1,196
3	7	0.4	0.089	1.50	1,310	3	7	0.4	0.099	1.74	1,449
3	8	0.4	0.078	1.27	1,169	3	8	0.4	0.068	1.06	1,041
3	9	0.4	0.120	2.27	1,726	3	9	0.4	0.119	2.24	1,712
3	10	0.4	0.123	2.34	1,762	3	10	0.4	0.084	1.41	1,254
3	11	0.4	0.128	2.49	1,833	3	11	0.4	0.066	1.03	1,018
3	12	0.4	0.111	2.04	1,605	3	12	0.4	0.095	1.65	1,395
3	13	0.4	0.192	4.57	2,753	3	13	0.4	0.165	3.61	2,351
3	14	0.4	0.154	3.26	2,197	3	14	0.4	0.156	3.33	2,226
3	15	0.4	0.166	3.65	2,367	3	15	0.4	0.160	3.47	2,290
3	16	0.4	0.142	2.89	2,028	3	16	0.4	0.184	4.29	2,637
3	17	0.75	0.090	7.59	3,859	3	17	0.75	0.116	10.64	4,832
3	18	0.75	0.108	9.70	4,544	3	18	0.75	0.109	9.82	4,562
3	Buoy 1	0.4	0.041	0.55	669	3	Buoy 2	0.4	0.066	1.03	1,018

NOTES.

Explosive, dynamite No. 1; charge, 15 pounds; submergence, 45 feet; depth of water, 88 feet; axis of crate, horizontal; case, can No. 3, sawdust tamping; ignition, Farmer dynamo and 1 service low tension fuze. Effects: A dome of yellow water rose midway between buoys to a height of 10 feet in one second after firing; crate somewhat bent, especially near middle, but not seriously so.

Details of experiments with the Crate—Continued.

SHOT 349—FIRED SEPTEMBER 23, 1874.

TOP OF CRATE.						BOTTOM OF CRATE.					
Gauge.		Lead cylinder.		Per square inch.		Gauge.		Lead cylinder.		Per square inch.	
Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.
No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*	*No.*		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*
3	1	0.4	0.070	1.10	1,065	3	1	0.4	0.064	0.99	900
3	2	0.4	0.059	0.87	912	3	2	0.4	0.063	0.96	974
3	3	0.4	0.063	0.96	974	3	3	0.4	0.060	0.89	925
3	4	0.4	0.067	1.05	1,030	3	4	0.4	0.083	1.38	1,239
3	5	0.4	0.107	1.94	1,550	3	5	0.4	0.015	2.13	1,655
3	6	0.4	0.101	1.79	1,474	3	6	0.4	0.086	1.45	1,279
3	7	0.4	0.097	1.69	1,422	3	7	0.4	0.113	2.09	1,630
3	8	0.4	0.091	1.55	1,336	3	8	0.4	0.114	2.11	1,643
3	9	0.4	0.132	2.60	1,890	3	9	0.4	0.131	2.58	1,878
3	10	0.4	0.147	3.05	2,101	3	10	0.4	0.150	3.15	2,147
3	11	0.4	0.140	2.83	2,000	3	11	0.4	0.131	2.58	1,878
3	12	0.4	0.133	2.63	1,903	3	12	0.4	0.148	3.09	2,116
3	13	0.4	0.220	5.71	3,192	3	13	0.4	0.207	5.15	2,982
3	14	0.4	0.239	6.54	3,497	3	14	0.4	0.228	6.05	3,317
3	15	0.4	0.240	6.59	3,513	3	15	0.4	0.210	5.28	3,031
3	16	0.4	0.229	6.09	3,333	3	16	0.4	0.229	6.09	3,333
3	17	0.75	0.129	12.27	5,315	3	17	0.75	0.141	13.83	5,758
3	18	0.75	0.150	15.07	6,097	3	18	0.75	0.089	7.49	3,824
3	Buoy 1	0.4	0.043	0.58	698	3	Buoy 2	0.4	0.071	1.12	1,078

NOTES.

Explosive, dynamite No. 1; charge, 20 pounds; submergence, 45 feet; depth of water, 90 feet; axis of crate, horizontal; case, can No. 3, nll; ignition, Farmer dynamo and 1 service low tension fuze. Effects: A jet 15 feet high and 20 feet in diameter rose between the buoys in about a second; a piece of coal on top of buoy was thrown 15 feet upward by shock; middle top transom, already weakened, was blown off, and whole crate was warped slightly.

SHOT 396—FIRED OCTOBER 5, 1875.

3	1	0.4	0.092	1.57	1,351	3	1	0.4	0.118	2.21	1,698
3	2	0.4	0.113	2.09	1,630	3	2	0.4	0.100	1.77	1,462
3	3	0.4	0.121	2.29	1,738	3	3	0.4	0.104	1.86	1,510
3	4	0.4	0.103	1.84	1,498	3	4	0.4	0.108	1.96	1,565
3	5	0.4	0.143	2.92	2,042	3	5	0.4	0.144	2.95	2,056
3	6	0.4	0.132	2.60	1,890	3	6	0.4	0.146	3.02	2,085
3	7	0.4	0.139	2.80	1,986	3	7	0.4	0.141	2.86	2,014
3	8	0.4	0.172	3.86	2,460	3	8	0.4	0.137	2.74	1,957
3	9	0.4	0.172	3.86	2,460	3	9	0.4	0.204	5.03	2,933
3	10	0.4	0.186	4.36	2,666	3	10	0.4	0.210	5.28	3,031
3	11	0.4	0.227	6.00	3,302	3	11	0.4	0.197	4.75	2,824
3	12	0.4	0.218	5.62	3,158	3	12	0.4	0.197	4.75	2,824
3	13	0.4	0.299	9.51	4,485	3	13	0.4	0.297	9.38	4,444
3	14	0.4	0.311	10.16	4,688	3	14	0.4	0.302	9.67	4,535
3	15	0.4	0.303	9.72	4,550	3	15	0.4	0.297	9.38	4,444
3	16	0.4	0.280	8.47	4,153	3	16	0.4	0.309	10.04	4,652
3	17	0.4	0.524	27.39	9,081	3	17	0.4	0.489	23.88	8,289
3	18	0.4	0.508	25.72	8,707	3	18	0.4	0.449	20.37	7,455
3	Buoy 1	0.4	0.058	0.85	899	3	Buoy 2	0.4	0.079	1.29	1,182

NOTES.

Explosive, dynamite No. 1; charge, 30 pounds; submergence, 32 feet; depth of water, 56 feet; axis of crate, horizontal; case, can No. 4, sawdust tamping; ignition, Farmer dynamo and 1 service low tension fuze. Effects: A jet between 30 and 40 feet high rose between the buoys, which were both corrugated; No. 1 showed a small leak, and its limit of strength was just reached; one diagonal brace, which had been added to stiffen the new middle transom, was twisted off, four bolts being sheared; the other new brace was loosened.

Details of experiments with the Crate—Continued.

SHOT 397—FIRED OCTOBER 8, 1875.

TOP OF CRATE.						BOTTOM OF CRATE.					
Gauge.		Lead cylinder.		Per square inch.		Gauge.		Lead cylinder.		Per square inch.	
Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.
No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*	*No.*		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*
3	1	0.4	0.163	3.55	2,327	3	1	0.4	0.147	3.05	2,101
3	2	0.4	0.164	3.58	2,339	3	2	0.4	0.174	3.93	2,491
3	3	0.4	0.179	4.11	2,565	3	3	0.4	0.137	2.74	1,957
3	4	0.4	0.169	3.75	2,414	3	4	0.4	0.120	2.27	1,726
3	5	0.4	0.204	5.03	2,933	3	5	0.4	0.176	4.01	2,521
3	6	0.4	0.212	5.36	3,061	3	6	0.4	0.148	3.09	2,116
3	7	0.4	0.214	5.44	3,092	3	7	0.4	0.187	4.39	2,680
3	8	0.4	0.259	7.44	3,807	3	8	0.4	0.161	3.50	2,302
3	9	0.4	0.315	10.39	4,758	3	9	0.4	0.177	4.04	2,536
3	10	0.4	0.290	8.96	4,311	3	10	0.4	0.247	6.89	3,617
3	11	0.4	0.299	9.51	4,485	3	11	0.4	0.189	4.47	2,709
3	12	0.4	0.317	10.51	4,800	3	12	0.4	0.228	6.05	3,317
3	13	0.4	0.425	19.13	7,149	3	13	0.4	0.391	15.57	6,231
3	14	0.4	0.413	17.33	6,687	3	14	0.4	0.382	14.85	6,039
3	15	0.4	0.411	17.16	6,646	3	15	0.4	0.407	16.85	6,465
3	16	0.4	......	......	......	3	16	0.4	0.410	17.08	6,626
3	17	0.75	0.310	43.02	12,272	3	17	0.75	0.301	41.07	11,895
3	18	0.75	0.296	39.95	11,677	3	18	0.75	0.331	47.65	13,137
3	Buoy 1	0.4	0.058	0.85	899	3	Buoy 2	0.4	0.109	1.99	1,579

NOTES.

Explosive, dynamite No. 1; charge, 50 pounds; submergence, 30 feet; depth of water, 50 feet; axis of crate, horizontal; case, can No. 4 full; ignition, Farmer dynamo and 1 service low tension fuze. Effects: Jet rose 50 to 60 feet, burying both buoys, and collapsing them and parting the hawsers; everything recovered; crate not injured seriously.

SHOT 398—FIRED OCTOBER 13, 1875.

3	1	0.4	0.171	3.83	2,445	3	1	0.4	0.191	4.54	2,738
3	2	0.4	0.201	4.90	2,883	3	2	0.4	0.179	4.11	2,565
3	3	0.4	0.186	4.36	2,666	3	3	0.4	0.149	3.11	2,132
3	4	0.4	0.313	......	......	3	4	0.4	0.196	4.72	2,810
3	5	0.4	0.246	6.84	3,602	3	5	0.4	0.217	5.57	3,141
3	6	0.4	0.227	6.00	3,302	3	6	0.4	0.205	5.07	2,949
3	7	0.4	0.192	4.57	2,753	3	7	0.4	0.179	4.11	2 565
3	8	0.4	0.214	5.44	3,092	3	8	0.4	0.181	4.18	2,594
3	9	0.4	0.286	8.77	4,249	3	9	0.4	0.309	10.04	4,652
3	10	0.4	0.340	......	......	3	10	0.4	0.300	9.57	4,505
3	11	0.4	0.267	7.82	3,937	3	11	0.4	0.234	6.31	3,414
3	12	0.4	0.277	8.32	4,104	3	12	0.4	0.236	6.41	3,447
3	13	0.4	0.383	14.93	6,060	3	13	0.4	0.443	19.80	7,426
3	14	0.4	0.381	14.78	6,017	3	14	0.4	......	......	......
3	15	0.4	0.433	18.97	7,110	3	15	0.4	0.461	21.35	7,692
3	16	0.4	0.439	19.45	7,229	3	16	0.4	0.473	22.38	7,935
3	17	0.75	0.307	42.38	12,121	3	17	0.75	0.320	45.28	12,697
3	18	0.75	0.238	28.84	9,397	3	18	0.75	0.419	71.82	17,268

NOTES.

Explosive, dynamite No. 1; charge, 40 pounds; submergence, 14 feet; depth of water, 19 feet; crate resting on muddy bottom, with planks under the two outer panels; case, can No. 4, sawdust tamping; ignition, 40 cells Leclanché firing battery and 1 service low tension fuze. Effects: Jet about 40 feet high; crate was somewhat warped, but not injured seriously.

Details of experiments with the Crate—Continued.

SHOT 399—FIRED OCTOBER 13, 1875.

TOP OF CRATE.						BOTTOM OF CRATE.					
Gauge.		Lead cylinder.		Per square inch.		Gauge.		Lead cylinder.		Per square inch.	
Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.	Kind.	Number.	Diameter.	Shortening.	Energy.	Pressure.
No.		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*	*No.*		*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*
3	1	0.4	0.236	6.41	3,447	3	1	0.4	0.182	4.22	2,608
3	2	0.4	0.187	4.39	2,680	3	2	0.4	0.247	6.89	3,617
3	3	0.4	0.177	4.04	2,536	3	3	0.4	0.217	5.57	3,141
3	4	0.4	0.213	5.40	3,077	3	4	0.4	0.246	6.84	3,602
3	5	0.4	0.197	4.75	2,824	3	5	0.4	0.308	9.98	4,634
3	6	0.4	0.238	6.50	3,480	3	6	0.4	0.289	8.91	4,296
3	7	0.4	0.247	6.89	3,617	3	7	0.4	0.273	8.12	4,037
3	8	0.4	0.276	8.27	4,087	3	8	0.4	0.311	10.16	4,688
3	9	0.75	......	......	......	3	9	0.75	0.179	19.31	7,192
3	10	0.75	0.170	18.00	6.864	3	10	0.75	0.179	19.31	7,192
3	11	0.75	0.142	13.96	5,792	3	11	0.75	0.101	8.84	4,273
3	12	0.75	0.157	16.08	6,367	3	12	0.75	0.109	9.82	4,582
3	13	0.75	0.250	31.09	9,880	3	13	0.75	0.331	......	......
3	14	0.75	0.272	35.00	10,694	3	14	0.75	0.265	33.82	10,452
3	15	0.75	0.307	42.37	12,149	3	15	0.75	0.280	36.75	11,050
3	16	0.75	0.220	25.92	8,752	3	16	0.75	0.260	32.98	10,280
3	17	0.75	0.577	132.4	25,960	3	17	0.75	0.519	106.7	22,490
3	18	0.75	0.576	131.0	25,780	3	18	0.75	0.559	123.5	24,780

NOTES.

Explosive, dynamite No. 1; charge, 100 pounds; submergence, 8 feet; depth of water, 13 feet; crate resting on muddy bottom; case, old model circuit closer buoy of ½ inch wrought iron; ignition, 40 cells Leclanché firing battery and 1 service low tension fuze. Effects: Fine jet 200 feet high; the weight of falling water crushed crate into the mud so that the ends rose above surface 28 feet apart; it was raised by successive tidal lifts and all the gauges were recovered; photographs showing its condition are preserved, the injuries being so serious that it was not repaired.

APPENDIX C.

DETAILS OF EXPERIMENTS WITH THE IRON TARGET.

SHOT 388—FIRED JUNE 10, 1875.

Gauge.		Charge to gauge.			Lead cylinder.			Per square inch.		
Kind.	Number.	Distance (D).	Angle from nadir (ϑ).		Diameter.	Shortening.	Observed energy.	Observed pressure.	Computed pressure.	Difference.
No.		*Feet.*	°	'	*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*	*Pounds.*	*Pounds.*
1	1	40.5	130	14	0.3	0.006	0.50	630	668	− 38
1	2	38.0	133	04	0.3	0.008	0.72	803	736	+ 67
1	3	35.4	138	10	0.3	0.001	0.08	186	821	− 635
1	4	38.0	133	04	0.3	0.012	1.18	1,117	736	+ 381
1	5	42.7	127	18	0.3	0.004	0.31	458	617	− 159
1	6	42.7	127	18	0.3	0.008	0.72	803	617	+ 186
1	7	40.4	130	23	0.3	0.003	0.23	375	671	− 296
1	8	36.4	136	19	0.3	0.011	1.06	1,039	786	+ 253
1	9	33.8	141	39	0.3	0.009	0.53	883	883	+ 0
1	10	33.8	141	39	0.3	0.003	0.23	375	883	− 508
1	11	36.4	136	19	0.3	0.011	1.06	1,039	786	+ 253
1	12	40.4	130	23	0.3	0.011	1.06	1,039	671	+ 368
1	13	44.8	125	12	0.3	0.005	0.39	530	582	− 52
1	14	39.1	132	07	0.3	0.006	0.50	630	705	− 75
1	15	32.0	145	52	0.3	0.014	1.42	1,263	961	+ 302
1	16	39.1	132	07	0.3	0.013	1.30	1,191	705	+ 486

NOTES.

Explosive, dynamite No. 1; charge, 20 pounds; submergence, 30 feet; location, 13 feet horizontally from No. 15 corner, on line prolonged from centre; depth of water, 42 feet; case, can No. 3, full; ignition, Farmer dynamo and 1 service low tension fuze. Effects: Jet 24 feet high; no injury to target.

SHOT 389—FIRED JUNE 10, 1875.

1	1	40.5	130	14	0.3	0.006	0.50	630	1,076	− 446
1	2	38.0	133	04	0.3	0.011	1.06	1,039	1,184	− 145
1	3	35.4	138	10	0.3	0.004	0.31	458	1,321	− 863
1	4	38.0	133	04	0.3	0.018	2.00	1,586	1,184	+ 402
1	5	42.7	127	18	0.3	0.005	0.39	530	993	− 463
1	6	42.7	127	18	0.3	0.009	0.83	883	993	− 110
1	7	40.4	130	23	0.3	0.008	0.72	803	1,080	− 277
1	8	36.4	136	19	0.3	0.014	1.42	1,263	1,266	− 3
1	9	33.8	141	39	0.3	0.014	1.42	1,263	1,421	− 158
1	10	33.8	141	39	0.3	0.007	0.61	719	1,421	− 702
1	11	36.4	136	19	0.3	0.020	2.30	1,742	1,266	+ 476
1	12	40.4	130	23	0.3	0.008	0.72	803	1,080	− 277
1	13	44.8	125	12	0.3	0.009	0.83	883	839	+ 44
1	14	39.1	132	07	0.3	0.010	0.94	959	1,135	− 176
1	15	32.0	145	52	0.3	0.022	2.58	1,880	1,547	+ 333
1	16	39.1	132	07	0.3	0.014	1.42	1,263	1,135	+ 128

NOTES.

Explosive, dynamite No. 1; charge, 40 pounds; submergence, 30 feet; location, 13 feet horizontally from No. 15 corner, on line prolonged from centre; depth of water, 42 feet; case, can No. 4, sawdust tamping; ignition, Farmer dynamo and 1 service low tension fuze. Effects: Loud ring; jet which buried target in spray; no injury.

Details of experiments with the Iron Target—Continued.

SHOT 390—FIRED JUNE 11, 1875.

Gauge.		Charge to gauge.		Lead cylinder.		Per square inch.			
Kind.	Number.	Distance (D).	Angle from nadir (ϑ).	Diameter.	Shortening.	Observed energy.	Observed pressure.	Computed pressure.	Difference.
No.		*Feet.*	° ′	*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*	*Pounds.*	*Pounds.*
1	1	30.2	173 17	0.3	0.017	1.84	1,501	1,458	+ 43
1	2	30.2		0.3	0.025	3.01	2,083		+ 625
1	3	30.2		0.3	0.020	2.30	1,752		+ 284
1	4	30.2		0.3	0.026	3.16	2,149		+ 691
1	5	30.8	166 04	0.3	0.014	1.42	1,263	1,400	− 137
1	6	30.8		0.3	0.014	1.42	1,263		− 137
1	7	30.8		0.3	.....	....	.....		......
1	8	30.8		0.3	0.024	2.87	2,018		+ 618
1	9	30.8		0.3	0.021	2.44	1,811		+ 211
1	10	30.8		0.3	.....	....	.....		......
1	11	30.8		0.3	0.016	1.69	1,418		+ 18
1	12	30.8		0.3	0.016	1.69	1,418		+ 18
1	13	31.4	162 02	0.3	0.020	2.30	1,742	1,353	+ 389
1	14	31.4		0.3	0.021	2.54	1,811		+ 458
1	15	31.4		0.3	0.020	2.30	1,742		+ 389
1	16	31.4		0.3	0.015	1.54	1,332		− 21

NOTES.

Explosive, dynamite No. 1; charge, 30 pounds; submergence, 32½ feet; location, central; depth of water, 39 feet; case, can No. 4, sawdust tamping; ignition, Farmer dynamo and 1 service low tension fuze. Effects: Target rose 1 foot squarely, settled back and rose again, when a jet burst up through central hole 15 to 20 feet high; showed leak, which caused it to sink in a couple of hours (see Plate XVI).

SHOT 391—FIRED AUGUST 17, 1875.

1	1	37.0	142 12	0.3	0.011	1.06	1,039	1,453	− 414
1	2	35.2	146 25	0.3	0.016	1.69	1,418	1,571	− 153
1	3	33.2	151 57	0.3	0.010	0.94	959	1,726	− 767
1	4	35.2	146 25	0.3	0.031	3.92	2,482	1,571	+ 911
1	5	38.9	138 42	0.3	0.014	1.42	1,263	1,347	− 84
1	6	38.9	138 42	0.3	0.021	2.41	1,811	1,347	+ 464
1	7	37.2	142 02	0.3	0.003	0.23	375	1,442	−1,067
1	8	34.1	149 05	0.3	0.030	3.75	2,412	1,652	+ 760
1	9	32.1	155 56	0.3	0.023	2.73	1,952	1,819	+ 133
1	10	32.1	155 56	0.3	0.016	1.69	1,418	1,819	− 401
1	11	34.1	149 05	0.3	0.024	2.87	2,018	1,652	+ 366
1	12	37.2	142 02	0.3	0.024	2.87	2,018	1,442	+ 566
1	13	40.7	135 52	0.3	0.021	2.44	1,811	1,256	+ 555
1	14	36.2	144 04	0.3	0.018	2.00	1,586	1,504	+ 82
1	15	31.0	161 17	0.3	0.030	3.75	2,412	1,932	+ 480
1	16	36.2	144 04	0.3	0.021	2.44	1,811	1,504	+ 307

NOTES.

Explosive, dynamite No. 1; charge, 50 pound submergence, 32½ feet; location, 5 feet horizontally from No. 15 corner, on line prolonged from centre; depth of water, 40 feet; case, can No. 4, full; ignition, Farmer dynamo and 1 low tension fuze. Effects: White jet 25 feet high and clear of target; no damage.

Details of experiments with the Iron Target—Continued.

SHOT 392—FIRED AUGUST 17, 1875.

Gauge.		Charge to gauge.			Lead cylinder.		Per square inch.			
Kind.	Number.	Distance (D).	Angle from nadir (ϑ).		Diameter.	Shortening.	Observed energy.	Observed pressure.	Computed pressure.	Difference.
No.		*Feet.*	°	′	*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*	*Pounds.*	*Pounds.*
1	1	39.5	139	25	0.3	0.013	1.30	1,191	1,780	— 589
1	2	36.6	142	12	0.3	0.016	1.69	1,418	1,933	— 515
1	3	34.5	147	22	0.3	0.012	1.18	1,117	2,121	—1,004
1	4	36.6	142	12	0.3	0.028	3.45	2,280	1,933	+ 347
1	5	40.6	135	07	0.3	0.013	1.30	1,191	1,648	— 457
1	6	40.6	135	07	0.3	0.016	1.69	1,418	1,648	— 230
1	7	39.6	139	18	0.3	0.012	1.18	1,117	1,774	— 657
1	8	35.4	144	55	0.3	0.021	2.44	1,811	2,042	— 231
1	9	33.2	151	07	0.3	0.031	3.92	2,482	2,256	+ 226
1	10	33.2	151	07	0.3	0.033	4.26	2,623	2,256	+ 367
1	11	35.4	144	55	0.3	0.025	3.01	2,085	2,042	+ 43
1	12	39.6	139	18	0.3	0.029	3.60	2,346	1,774	+ 572
1	13	42.5	132	31	0.3	0.023	2.73	1,952	1,536	+ 416
1	14	37.6	140	22	0.3	0.023	2.73	1,952	1,854	+ 98
1	15	32.8	156	45	0.3	0.031	3.92	2,482	2,322	+ 160
1	16	37.6	140	22	0.3	0.026	3.16	2.149	1,854	+ 295

NOTES.

Explosive, dynamite No. 1; charge, 75 pounds; submergence, 32¾ feet; location, 8 feet horizontally from No. 15 corner, on line prolonged from centre; depth of water, 40 feet; case, old model buoy of ¼ inch iron; ignition, Farmer dynamo and 1 service low tension fuze. Effects: Jet discolored by mud rose close to target, throwing gravel and stones on board; no damage.

SHOT 393—FIRED AUGUST 17, 1875.

1	1	36.7	142	18	0.3	0.023	2.73	1,952	2,332	— 380
1	2	34.2	147	02	0.3	0.027	3.31	2,215	2,600	— 385
1	3	36.7	142	18	0.3	0.016	1.69	1,418	3,332	— 914
1	4	39.0	138	49	0.3	0 035	4.60	2,764	2,126	+ 638
1	5	38.5	137	58	0.3	0.026	3.16	2,149	2,163	— 14
1	6	35.2	144	41	0.3	0.037	4.97	2,908	2,488	+ 420
1	7	33.2	151	07	0.3	0.040	5.53	3,125	2,733	+ 392
1	8	33.2	151	07	0.3	0.036	4.79	2,836	2,733	+ 103
1	9	35.2	144	41	0.3	0.039	5.34	3,053	2,488	+ 565
1	10	38.5	137	58	0.3	0.019	2.15	1,664	2,163	— 499
1	11	40.8	135	24	0.3	0.033	4.26	2,623	1,981	+ 642
1	12	40.8	135	24	0.3	0.036	4.79	2,836	1,981	+ 855
1	13	37.6	140	22	0.3	0.034	4.43	2,694	2,245	+ 449
1	14	31.8	155	58	0.3	0.043	6.05	3,317	2,931	+ 386
1	15	37.6	140	22	0.3	0.021	2.44	1,811	2,245	— 434
1	16	42.8	132	05	0.3	0.024	2.87	2,018	1,843	+ 175

NOTES.

Explosive, dynamite No. 1; charge, 100 pounds; submergence, 31¾ feet; location, 8 feet horizontally from No. 14 corner, on line prolonged from centre; depth of water, 40 feet; case, buoyant torpedo, model, 1872; ignition, Farmer dynamo and 1 service low tension fuze. Effects: Severe shock; jet broke a little under the corner and caused a very slight leak; one ⅞ inch bolt head torn off.

Details of experiments with the Iron Target—Continued.

SHOT 394—FIRED AUGUST 19, 1875.

Gauge.		Charge to gauge.		Lead cylinder.		Per square inch.			
Kind.	Number.	Distance (D).	Angle from nadir (ϑ).	Diameter.	Shortening.	Observed energy.	Observed pressure.	Computed pressure.	Difference.
No.		*Feet.*	° ′	*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*	*Pounds.*	*Pounds.*
1	1	30.1	154 57	0.3	0.006	0.50	630	3,159	−2,529
1	2	30.1	154 57	0.3	0.032	4.09	2,553	3,159	− 606
1	3	28.4	163 50	0.3	0.018	2.00	1,586	3,487	−1,901
1	4	28.4	163 50	0.3	0.041	5.70	3,189	3,487	− 298
1	5	30.7	152 39	0.3	0.004	0.31	458	3 062	−2,604
1	6	32.0	148 34	0.3	0.028	3.45	2,280	2,866	− 586
1	7	32.0	148 34	0.3	0.005	0.39	530	2,866	−2,336
1	8	30.7	152 39	0.3	0.040	5.53	3,125	3,062	+ 63
1	9	29.0	159 59	0.3	0.031	3.92	2,482	3,414	− 932
1	10	27.6	171 02	0.3	0.024	2.87	2,018	3,677	−1,659
1	11	27.6	171 02	0.3	0.014	1.42	1,263	3,677	−2,414
1	12	29.0	159 59	0.3	0.046	6.58	3,509	3,414	+ 95
1	13	32.5	146 56	0.3	0.008	0.72	803	2,793	−1,990
1	14	32.5	146 56	0.3	0.044	6.23	3,381	2,793	+ 588
1	15	28.2	164 49	0.3	0.018	2.00	1,586	3,480	−1,894
1	16	28.2	164 49	0.3	0.040	5.53	3,125	3,480	− 355

NOTES.

Explosive, dynamite No. 1; charge, 100 pounds; submergence, 30 feet; location, under edge, between Nos. 10 and 11; depth of water, 40 feet; case, old model buoy of ¼ inch iron; ignition, Farmer dynamo and 1 service low tension fuze. Effects: High jet, burying target; bulged in side compartments slightly and caused small leak; top showed a bending upward into a dome shape. See page 135 in connection with recorded lengths of odd numbered gauges (which are vitiated).

SHOT 395—FIRED AUGUST 19, 1875.

1	1	18.9	155 16	0.3	0.008	0.72	803	6,058	−5,255
1	2	18.9	155 16	0.3	0.041	5.70	3,189	6,058	−2,869
1	3	21.4	143 26	0.3	0.007	0.61	719	4,971	−4,252
1	4	21.4	143 26	0.3	0.044	6.23	3,381	4,971	−1,590
1	5	19.9	150 05	0.3	0.017	1.84	1,501	5,581	−4,080
1	6	17.7	164 54	0.3	0.050	7.31	3,764	6,772	−3,008
1	7	17.7	164 54	0.3	0.007	0.61	719	6,772	−6,053
1	8	19.9	150 05	0.3	0.061	9.71	4,547	5,581	−1,034
1	9	22.2	140 33	0.3	0.025	3.01	2,083	4,702	−2,619
1	10	24.0	135 57	0.3	0.017	1.84	1,501	4,177	−2,676
1	11	24.0	135 57	0.3	0.015	1.54	1,332	4,177	−2,845
1	12	22.2	140 33	0.3	0.044	6.23	3,381	4,702	−1,321
1	13	18.7	156 45	0.3	0.046	6.58	3,509	6,175	−2,666
1	14	18.7	156 45	0.3	0.066	10.59	4,817	6,175	−1,358
1	15	24.7	134 53	0.3	0.012	1.18	1,117	4,001	−2,884
1	16	24.7	134 53	0.3	0.044	6.23	3,381	4,001	− 620

NOTES.

Explosive, dynamite No. 1; charge, 100 pounds; submergence, 20 feet; location, under edge, between Nos. 6 and 7; depth of water, 40 feet; case, old model buoy of ¼ inch iron; ignition, Farmer machine and 1 service low tension fuze. Effects: Caused leak which sunk target in 1¾ hours; chains scored edges, but held; jet high. See page 135 in connection with recorded lengths of odd numbered gauges (which are vitiated).

Details of experiments with the Iron Target—Continued.

SHOT 428—FIRED AUGUST 18, 1876.

Gauge.		Charge to gauge.		Lead cylinder.		Per square inch.			
Kind.	Number.	Distance (D).	Angle from nadir (ϑ).	Diameter.	Shortening.	Observed energy.	Observed pressure.	Computed pressure.	Difference.
No.		*Feet.*	° ′	*Inches.*	*Inches.*	*Foot-lbs.*	*Pounds.*	*Pounds.*	*Pounds.*
1	1	30.2	173 17	0.4	.....	.....	.....	5,167	......
1	2	30.2		0.4	0.050	12.03	5,215		+ 48
1	3	30.2		0.4	0.039	8.81	4,264		— 903
1	4	30.2		0.4	0.050	12.03	5,215		+ 45
1	5	30.8	166 04	0.4	0.041	9.37	4,440	4,959	— 519
1	6	30.8		0.4	0.039	8.81	4,264		— 695
1	7	30.8		0.4	0.041	9.37	4,440		— 559
1	8	30.8		0.4	0.049	11.71	5,127		+ 168
1	9	30.8		0.4	0.041	9.37	4,440		— 559
1	10	30.8		0.4	0.039	8.81	4,264		— 695
1	11	30.8		0.4	0.038	8.53	4,172		— 787
1	12	30.8		0.4	0.055	13.50	5,666		+ 707
1	13	31.4	162 02	0.4	0.030	6.36	3,431	4,792	—1,361
1	14	31.4		0.4	0.043	9.91	4,608		— 184
1	15	31.4		0.4	0.049	11.71	5,127		+ 335
1	16	31.4		0.4	0.039	8.81	4,264		— 528

NOTES.

Explosive, dynamite No. 1; charge, 200 pounds; submergence, 32¾ feet; location, central; depth of water, 42 feet; case, ground torpedo, model of 1873; ignition, 40 cells Leclanché battery and 1 service low tension fuze. Effects: Parted 7 chains, 1 anchor ring, and 1 shackle; raised target 3 feet before it was buried in jet; caused leak, which sunk it in 30 minutes.

SHOT 478—FIRED SEPTEMBER 12, 1877.

Kind.	Number.	Distance (D).	Angle from nadir (ϑ).	Diameter.	Shortening.	Observed energy.	Observed pressure.	Computed pressure.	Difference.
1	1	10.6	160 33	0.4	0.061	15.47	6,203	21,855	—15,652
1	2	10.6		0.4	0.068	17.74	6,797		—15,058
1	3	10.6		0.4	0.066	17.07	6,624		—15,231
1	4	10.6		0.4	0.081	22.31	7,918		—13,937
1	5	12.2	145 12	0.4	0.081	22.31	7,918	17,393	— 9,475
1	6	12.2		0.4	0.045	10.45	4,776		—14,617
1	7	12.2		0.4	0.066	17.07	6,624		—10,769
1	8	12.2		0.4	0.066	17.07	6,624		—10,769
1	9	12.2		0.4	0.069	18.08	6,884		—10,509
1	10	12.2		0.4	0.060	15.15	6,119		—11,174
1	11	12.2		0.4	0.070	18.42	6,971		—10,422
1	12	12.2		0.4	0.051	12.32	5,305		—12,088
1	13	13.6	137 29	0.4	0.075	20.08	7,382	14,703	— 7,321
1	14	13.6		0.4	0.058	14.49	5,938		— 8,865
1	15	13.6		0.4	0.052	12.62	5,395		— 9,308
1	16	13.6		0.4	0.069	18.08	6,884		— 7,819

NOTES.

Explosive, dynamite No. 1; charge, 200 pounds; submergence, 13 feet; location, central; depth of water, 30 feet; case, buoyant torpedo, model of 1872; ignition, 40 cells Leclanché battery and 1 service low tension fuze. Effects: Target instantly hidden by jet; when latter subsided it was seen laboring in the vortex for a few seconds and then sank.

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